# Modelling the growth, feed intake and backfat deposition of different South African sheep breed types

by

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# Declaration

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# Summary

In order to set up a decision support system which can be applied to the feedlot finishing of lambs, models relating to the growth and production of lambs need to be developed. This dissertation presents the details of studies to develop models to describe growth, feed intake, back-fat deposition and wool growth, as well as describe meat, wool and leather quality characteristics of lambs of different breeds. The breeds that were included in the various studies consisted of ewes and rams from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, Namaqua Afrikaner, South African Mutton Merino (SAMM) and White Dorper sheep. In the respective studies, the lambs were reared under optimal growth conditions from birth up until one year of age when they were assumed to have attained a mature body weight. In the growth studies, growth was monitored on a weekly basis from birth, while intake studies commenced when lambs were weaned at ~90 days of age. Measurement of the backfat and *longissimus* muscle depths was performed using ultrasound scans every two weeks after lambs attained body weights of 20 kg. Wool growth of the lambs was measured using the midrib patch production technique on a monthly basis until lambs were shorn when they attained a mature body weight at one year of age. Appropriate non-linear regressions were fitted to the respective curves of each individual and parameter values were then analysed to test for differences between sexes and breeds. The Logistic, Gompertz and Von Bertalanffy functions were found to appropriately model the sigmoidal growth curves of the various production groups from birth until a mature live weight. On a standard feedlot diet (9.92 MJ ME/kg and 16% crude protein), daily intakes of the different breeds followed a curvilinear trend when plotted against body weight. This trend was modelled using a quadratic function. The peak dry matter intakes estimated from the model for the different breeds were 2203 g/day, 2007 g/day and 1958 g/day for Dormer, Dorper and SAMM breeds, respectively, observed at body weights between 60-70 kg. White Dorper (1879 g/day), Meatmaster (1780 g/day), Dohne Merino (1744 g/day,) and Merino (1560 g/day) lambs obtained peak intakes at ~58 kg body weight. While the quadratic model can be used to observe trends in intake, more accurate linear models can be obtained by modelling the intake expressed as a percentage of body weight against the body weight of the lambs. Similarly, the regressions of cumulative intake with body weight ensured for accurate predictions to be made. The wool producing breeds were assessed to determine wool production rates. Merino sheep were found to have the highest wool growth rates (12.9 g/day) and finest fibre diameter (<20 μm), while Dormer lambs had the lowest wool growth rates (8.5 g/day) and coarsest fibre diameters (>27 μm). Dual-purpose Dohne Merino and SAMM lambs did not differ in terms of wool growth rate (10.1 g/day), though fleeces from Dohne Merino sheep had finer fibre diameters than that of SAMM (21.0 μm and 23.3 μm, respectively; $P \leq 0.05$). Fat deposition, measured using ultrasound scans, could be modelled with body weight (20-65 kg) of the lambs using the exponential function with moderate success. These models showed that early maturing breeds such as the White Dorper and Meatmaster deposit fat at an earlier stage and

have greater subcutaneous fat depths at a given body weight than Dorper sheep, which in turn exhibits greater fat deposition than the Dohne Merino, Dormer and SAMM breeds. After modelling the subcutaneous fat depth of the lambs, the ideal slaughter weights of the different breeds could be determined in order to produce a premium lamb carcass in terms of fat cover classification. In a feedlot study where back-fat was monitored, lambs with a back-fat depth of ~4 mm were selected for slaughter and the point of slaughter was taken as the ideal marketing weight. Early maturing Namaqua Afrikaner and Meatmaster sheep had the lowest ideal slaughter weights (32 kg and 35 kg, respectively), followed by Dorper sheep (38 kg) and later maturing Merino, Dohne Merino, Dormer and SAMM breeds (43- 45 kg). Dormer lambs were found to have highest growth rates (438 g/day) and desirable feeding efficiencies (3.71 kg feed/ kg weight gain) in the feedlot; whereas Namaqua Afrikaner lambs exhibited slow growth rates (~169 g/day) with unfavourable feeding efficiencies (~7.08 kg feed/ kg weight gain). The characteristics of the premium lamb carcasses of the various breeds fell within the expectations outlined by the South African carcass classification system, with meat quality traits showing small differences and so indicating a relatively uniform meat product. While the quality characteristics of the different breeds did not vary greatly, the carcasses of fat-tailed breeds differed in composition and conformation to the other breeds, with a majority of the carcass fat being deposited surrounding the tail, with a less developed forequarter region. Sheepskins obtained from the sheep that were slaughtered at the end of growth studies were tanned and the leather characteristics evaluated. Hair type breeds (White Dorper, Meatmaster and Dorper), on average, produced sheepskin leather with a stronger tensile strength (15.23 N/mm$^2$ *vs.* 9.31 N/mm$^2$; $P \leq 0.05$) and so could be shaved to a thinner, more pliable thickness (1.36 mm *vs.* 1.78 mm; $P \leq 0.05$) than that of wool type breeds. Skins from hair type breeds also produced a more favourable nappa leather product, while skins from wool type breeds should possibly be used for wool-on leather products.

The models and results obtained in the above studies can be used to run simulations of feedlot rearing situations of different sheep breeds and predict the possible outcomes. Ideal slaughter weights for the lambs, in terms of market specifications, or optimal profitability can then be determined to assist the producers in decision making. The results also indicate the product quality of meat, wool and leather from the different breeds, which can assist the producer as well as processor in deciding on the most appropriate marketing strategy for optimal profitability.

# Opsomming

Om 'n besluitnemingsondersteuningstelsel op te stel, wat toegepas kan word op die voerkraalafronding van lammers, moet modelle rakende die groei en produksie van lammers ontwikkel word. Hierdie proefskrif bevat die besonderhede van studies om modelle te ontwikkel om groei, voerinname, rugvetneerlegging en wolgroei, sowel as vleis-, wol- en leergehalte-eienskappe van lammers van verskillende rasse te beskryf. Die rasse wat by die verskeie studies ingesluit is, bestaan uit ooie en ramme van Dohne Merino, Dormer, Dorper, Meatmaster, Merino, Namaqua Afrikaner, Suid-Afrikaanse Vleismerino (SAVM) en Witdorper. In die onderskeie studies is die lammers grootgemaak onder optimale groeitoestande vanaf geboorte tot en met die ouderdom van een jaar, toe dit aanvaar word dat hulle 'n volwasse liggaamsmassa behaal het. In die groei studies is groei vanaf die geboorte weekliks gemonitor, terwyl innames studies begin het met lammers op ‘n ouderdom van ~90 dae. Die meting van rugvet en *longissimus* spier weefsel dieptes was uitgevoer met behulp van ultraklank skanderings is elke twee weke nadat lammers liggaams gewigte van 20 kg bereik het. Wolgroei van lammers is op 'n maandelikse basis gemonitor deur die midribkolproduksie-tegniek totdat die lammers geskeer is toe hul 'n volwasse liggaamsgewig bereik het op jaar oud ouderdom. Gepaste nie-lineêre regressies is op die onderskeie kurwes van elke individu gepas en parameter waardes is daarna ontleed om te toets vir verskille tussen geslagte en rasse. Die Logistic, Gompertz en Von Bertalanffy-funksies is gevind om die sigmoïedale groei kurwes van die verskillende produksiegroepe vanaf geboorte tot 'n volwasse lewende gewig toepaslik te modelleer. Op 'n standaard voerkraal-dieet (9,92 MJ ME / kg en 16% ruwe proteïen), het die daaglikse inname van die verskillende rasse 'n kurwilinieêre neiging gevolg wanneer dit teen liggaamsmassa geplot is. Hierdie neiging is gemodelleer met behulp van 'n kwadratiese funksie. Die hoogste droëmateriaal inname wat geskat is van die model vir die verskillende rasse was 2203 g/dag, 2007 g/dag en 1958 g/dag onderskeidelik vir Dormer, Dorper en SAVM rasse, waargeneem by liggaams gewigte tussen 60-70 kg. Witdorper (1879 g/dag), Meatmaster (1780 g/dag), Dohne Merino (1744 g/dag) en Merino (1560 g/dag) lammers het 'piek inname op ~58 kg liggaamsgewig verkry. Terwyl die kwadratiese model gebruik kan word om neigings in die inname waar te neem, kan meer akkurate lineêre modelle verkry word deur die inname te modelleer uitgedruk as 'n persentasie liggaamsgewig, teenoor die liggaamsgewig van die lammers. Soortgelyk het die regressies van kumulatiewe inname teenoor liggaamsmassa akkurate voorspellings verseker. Die wolproduserende rasse is geassesseer om die wolproduksie tempo te bepaal. Merino skape het die hoogste wolgroei tempo (12.9 g/dag) en die fynste veseldiktes (<20 µm) gehad, terwyl Dormer-lammers die laagste wolgroei tempo (8.5 g/dag) en die grofste veseldiktes (>27 µm) gehad het. Dubbeldoel Dohne Merino en SAVM lammers het nie verskil in terme van wolgroei tempo nie (10.1 g/dag), hoewel vagte van Dohne Merino skape fyner veseldiktes gehad het as dié van SAVM (21.0 µm en 23.3 µm; $P \leq 0.05$). Vetneerlegging, gemeet met behulp van ultraklank-skanderings, kan met

liggaamsgewig (20-65 kg) van die lammers gemodelleer word met die gebruik van die eksponensiële funksie met matige sukses. Hierdie modelle het getoon dat vroeëvolwassende rasse soos die Witdorper en Meatmaster vet op ‘n vroeër stadium neerlê en dikker onderhuidse vetdiktes op 'n gegewe liggaamsgewig het as Dorper skape, wat weer hoër vetneerlegging toon as die Dohne Merino, Dormer en SAVM rasse. Nadat die onderhuidse vetdiktes van die lammers gemodelleer kon word, kon die ideale slaggewigte van die verskillende rasse bepaal word om 'n premiegraad lamkarkas te lewer in terme van die vetbedekking. In 'n voerkraal studie waar rugvet gemonitor was, is lammers met 'n rugvetdikte van ~4 mm geselekteer om te slag en die slagpunt word as die ideale bemarkings gewig beskou. Vroeëvolwassende Namaqua Afrikaner en Meatmaster skape het die laagste ideale slaggewigte gehad (32 kg en 35 kg, onderskeidelik), gevolg deur Dorper skape (38 kg) en latervolwassende Merino, Dohne Merino, Dormer en SAVM (43-45 kg) rasse. Dormer lammers het die hoogste groeitempo (438 g/dag) en die mees gewenste voerdoeltreffendheid (3,71 kg voer/kg gewigstoename) in die voerkraal getoon; terwyl die Namakwa-Afrikaner lammers 'n stadige groeitempo (~169 g/dag) met ‘n ongunstige voerdoeltreffendheid (~7,08 kg voer/kg gewigstoename) vertoon het. Die eienskappe van die premiegraad lam karkasse van die verskillende rasse het verwagtinge soos uiteengesit deur die Suid Afrikaanse karkas klassifikasie stelsel bereik, met klein verskille in vleis kwaliteit eienskappe getoon en dus 'n relatiewe eenvormige vleis produk aan te dui. Terwyl die vleis kwaliteit eienskappe nie grootliks verskil het nie tussen die rasse, die karkasse van vetstert-rasse het egter verskil in samestelling en bouvorm van die ander rasse, met die meerderheid van die karkasvet wat rondom die stert neergelê is, en met 'n minder ontwikkelde voorkwart. Skaapvelle wat verkry is van die skape wat aan die einde van die groei studies geslag is, is gelooi en die leereienskappe is geëvalueer. Haartipe rasse (Witdorper, Meatmaster en Dorper) het op gemiddeld, skaapvel leer met 'n sterker treksterkte geproduseer (15.23 N / mm2 *vs*. 9.31 N/mm$^2$; $P \leq 0.05$) wat dus tot 'n dunner, meer soepel dikte geskeer kon word (1.36 mm teenoor 1.78 mm; $P \leq 0.05$) as dié van wol rasse. Velle van haartipes lewer 'n meer gunstiger nappa-leerproduk, terwyl velle van wolrasse moontlik vir wol-aan-leer produkte gebruik moet word.

Die modelle en resultate wat in die bogenoemde studies verkry is, kan gebruik word om simulasies van voerkraal-situasies van verskillende skaaprasse uit te voer en die moontlike uitkomste te voorspel. Ideale slaggewigte vir die lammers, in terme van die mark spesifikasies, of optimale winsgewendheid kan dan bepaal word om die produsente te help met die besluitneming. Die resultate dui ook op die produk kwaliteit van vleis, wol en leer van die verskillende rasse, wat die produsent sowel as die verwerker kan help om te besluit oor die geskikste bemarkingstrategie vir optimale winsgewendheid.

This dissertation is dedicated to the memory of my late cousin
Gert Cornelius Van der Merwe (1993 - 2016).

# Biographical sketch

Daniël was born in Zimbabwe and grew up on a dairy farm in the Featherstone district, South of Harare. Growing up, Daniël assisted his family on the farm with the dairy and beef herds as well as helping with the management of the small sheep flock. Due to the political situation of the country at the time, the family later could not continue farming and had to relocate to the city when Daniel was 17 years old. After finishing school, eager to develop his fondness for working with animals, Daniël enrolled for a BSc Agric (Animal Science) degree at Stellenbosch University. Upon graduating in 2013, he decided to pursue postgraduate studies and completed a MSc degree with the dissertation title "Developing a model for feedlot production of Boer goat slaughter kids" in collaboration with Stellenbosch University and Western Cape Agricultural Research Trust. Inspired by discussions with Prof Tertius Brand on developing models for a decision support system that could be used to predict the feedlot production performance of various sheep breeds, Daniël (with an additional push from Prof Louw Hoffman) decided to undertake a doctoral study in order to develop these models.

It is a dream of his to be able to implement the skills and knowledge gathered from his studies to provide technical assistance to livestock producers, so as to intensify production and improve profitability and sustainability.

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- The Lord for directing me on the path to pursue and complete this study and granting me the opportunities that have come my way.

# Preface

This dissertation is presented as a compilation of 10 chapters. Each chapter is introduced separately, and citations are referenced according to the style of the peer-review journal Small Ruminant Research. This thesis represents a compilation of manuscripts, where each chapter is an individual entity.

# Outputs

**The following chapters have been published in peer reviewed journals:**

**Chapter 3 Application of growth models to different sheep breed types**

- Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019. Application of growth models to different sheep breed types in South Africa. *Small Rumin. Res.*, 178, 70- 78. https://doi.org/10.1016/j.smallrumres.2019.08.002

**The following work from this study has been presented as posters or oral presentations at national and international symposia:**

- Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2017. Modelling the feed intake of six commercial South African sheep breeds in a feedlot. *50$^{th}$ South African Society of Animal Science Congress.* 18-21 September 2017. Port Elizabeth, South Africa. (Poster presentation).
- Swart, E., Brand, T.S., Van der Merwe, D.A., 2018. Correction of ultrasound scanning of back-fat thickness to corresponding carcass composition of six sheep breeds. *36$^{th}$ South African Society of Agricultural Technologists SASAT Congress*. 18-21 September 2018. Hazyview, South Africa. (Poster presentation).
- Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019. Modelling the growth of seven commercial South African sheep breeds. *51$^{st}$ South African Society of Animal Science Congress.* 9-14 June 2019. Bloemfontein, South Africa. (Oral presentation).
- Van der Merwe, D.A., Brand, T.S., Hoffman, L.C. 2019. Modelling subcutaneous fat deposition in growing South African lambs. *65$^{th}$ International Congress of Meat Science and Technology.* 4-9 August 2019. Potsdam, Germany. (Poster presentation).

# List of abbreviations

| | |
|---|---|
| ADG | – Average daily gain |
| AIC | – Akaike information criterion |
| CFI | – Cumulative feed intake |
| C.V. | – Coefficient of variation of fibre diameter |
| DMI | – Daily dry matter intake |
| DSS | – Decision support system |
| FCR | – Feed conversion ratio |
| LSM | – Least square mean |
| pH24 | – Carcass pH measured 24 hours post-slaughter |
| pH30 | – Carcass pH measured 30 minutes post-slaughter |
| PI | – Percentage intake |
| RFID | – Radio frequency identification |
| RMSE | – Root mean square error |
| RUP | – Rumen undegradable protein |
| SAMM | – South African Mutton Merino |
| S.D. | – Standard deviation of fibre diameter |
| S.E. | – Standard error |
| TDN | – Total digestible nutrients |
| VFI | – Voluntary feed intake |
| W | – Body weight |

# Table of contents

# Chapter 1 - General introduction

Approximately 87.5% of agricultural land in South Africa is deemed unsuitable for crop production (FAOSTAT, 2019) with vast areas of pastoral land primarily being used for beef and dairy production, whilst sheep production mostly occurs in extensive systems in semi-arid and arid biomes that are unsuitable for other agricultural practices. Sheep production is also incorporated into mixed agriculture systems, where farmers allow their sheep to graze on cultivated cereal stubbles in order to increase their income per hectare from grain and sheep production. Currently, the South African national flock is estimated at 19.9 million head of sheep (DAFF, 2019). The benefit of sheep production is that an income can be generated from the wool, from the Merino type breeds, as well as from meat production; with South Africa producing about 48 200 tonnes of wool and 177 000 tonnes of meat per annum (DAFF, 2019). However, favourable meat prices that are offered to the producer, mean that a higher portion of the income generated from sheep production is as a result of marketing slaughter lambs. This drives producers to increase the level of production to enhance income and profitability. Along with this pressure to increase production so as to also meet consumer demands for lamb meat, producers face the challenge that the area of grazing land with sufficient forage resources is limited; much of the natural veld in South Africa is stocked to capacity, with overstocking resulting in a long-term reduction in grazing capacity (Tainton, 1988). Particularly in the more arid Karoo biomes that are primarily utilised for small stock production, stocking densities often exceed the long-term grazing capacity (Vorster *et al*., 1983). It is also predicted that as a result of climate change, with conditions becoming hotter and drier and droughts becoming more frequent, the composition and quality of the veld will change leading to less forage available for livestock grazing (Rust & Rust, 2013). Therefore, the competition for grazing will increase along with the pressure to maintain production levels. Farmers have already started to implement intensive management strategies so as to enhance production levels by improving reproduction in order to produce more lambs; as well as to make use of feedlot finishing so as to market high quantities of lamb that produce a high-quality carcass.

Feedlotting is the practice of adding value to animals with a low body weight and poor conformation by subjecting them to intensive feeding in order to produce a carcass with improved musculature and more desirable fat cover. Young animals are typically introduced to the feedlot soon after weaning so as to take advantage of their pre-puberty high growth rates and so ensure production efficiency. This also takes advantage of complimentary growth in lambs that did not receive adequate nutrition for growth prior to weaning (Addah *et al*., 2017). Lambs entering a feedlot weigh between 25 kg to 35 kg and are provided a concentrated ration in order to promote muscle growth and fat deposition to attain the desired carcass. With producers not being able to control the price of the lambs that they market, they need to manage the variables (such as nutrition and management) that are under their control, to ensure efficiency of production (Raineri *et al*., 2015). Profit margins in a feedlot finishing system are therefore narrow and rely on the economics of scale in order to cover production costs. Feedlotting is an intensive operation, rearing large numbers of lambs at the same time with a rapid throughput of lambs for slaughter. This benefits producers, as the entry of lambs in feedlots at a lower live weight reduces the number of grazing animals on the veld, alleviating the grazing pressure. In intensive systems, this allows for a greater number of stock ewes to be kept to produce lambs, thereby further increasing the production per hectare.

While feedlots rear a greater number of lambs on a smaller area of land, in order to ensure profitability, feedlots must strive for uniformity in the carcasses that they produce, which also meet market and consumer expectations. In the classification of lamb carcasses, the level of fat cover plays a significant role in determining the value of the carcass, both in the South African red meat classification system (Bruwer *et al*.,1987) as well as in other international carcass classification systems (Sañudo *et al*., 2000; Kosulwat *et al*., 2003; Andrade *et al.,* 2017). Therefore, in order to obtain the premium prices offered for the desired fat cover (South African A2 lamb, 1-4 mm back-fat depth; Government Notice, R863, 2006), producers must rear their lambs to a slaughter weight that coincides with this level of subcutaneous fat cover to ensure optimal probability. Brand *et al*. (2018) previously reported that to obtain this classification, Dorper lambs should be reared to a live weight of 36 kg and Merino and South African Mutton Merino lambs should be reared to a live weight of 42 kg. Evidently, these breeds differ in terms of maturity and fat deposition characteristics and so they differ in slaughter weights. While differences in the production and fat deposition of these breed types have been reported (Brand *et al*., 2017); it is important to the industry that more breeds that make up the industry are studied in order to assess their production characteristics and determine optimal slaughter weights for the breeds. The South African sheep industry consists of a number of breeds that are farmed for either wool or meat production, as well as dual-purpose breeds, with indigenous fat-tailed breeds also being reared to survive and produce under arid conditions (Cloete & Olivier, 2010).

The breeds selected in this study represent the most common sheep breeds herded in South African commercial systems, across the range of production types, as well as the indigenous Namaqua Afrikaner breed. The Merino is globally regarded as the most popular wool producing sheep breed and exhibits better wool growth than live weight growth characteristics compared to other breeds (Brand & Franck, 2000). The Dohne Merino is a dual-purpose breed, with an emphasis on wool production, developed from the Merino as well as German Mutton Merino breeds. The Dohne Merino presents improved growth compared to the Merino, while producing a lighter fleece but with similar fibre diameter (Cloete *et al*., 2001).

The South African Mutton Merino (SAMM) is also derived from the German Mutton Merino and presents high growth characteristics, but lower wool production potential than the Merino or Dohne Merino (Cloete *et al*., 2001) and is thus considered to be a dual-purpose breed with an emphasis on meat production. The Dormer is used as a terminal sire breed developed by crossing the Dorset Horn and SAMM to obtain a sheep with an improved carcass that is able to survive South African conditions (Cloete & Olivier, 2010). The Dorset Horn was also used in crosses with the Blackhead Persian sheep, to give rise to the Dorper which is a meat type breed known for its growth and adaptability to arid and semi-arid conditions (Cloete *et al*., 2000). The White Dorper was bred in a similar manner to the Dorper, selecting for an all-white sheep; also incorporating Van Rooy crosses into the selection (Milne, 2000). The Dorper is also renowned as an early maturing breed and presents high levels of fat deposition at younger ages (Cloete *et al*., 2000). The Meatmaster breed has been established more recently compared to the other breeds in this study, and is a composite fat-tailed breed made up of combinations of indigenous fat-tailed breeds (predominantly Damara) as well as meat type sire lines to yield a sheep breed that can survive harsh conditions with a good reproduction and meat production capacity (Peters *et al*., 2010). While the Namaqua Afrikaner breed is not typically herded in commercial production systems, it represents an unimproved indigenous fat-tailed breed commonly herded by smallholder farmers, mostly under arid environmental conditions (Qwabe *et al*., 2013).

The different breeds mentioned, vary in terms of their production potential, according to the selection pressures that the breeds were exposed to for either wool or meat production. It is therefore important to be able to evaluate their production performance under feedlot conditions, as well as to predict the change in these performance characters in growing lambs in order to adjust the management strategies applicable to the different types of lambs (Bello *et al*., 2016). In an era where precision livestock rearing is moving to the forefront, technology is being used to improve the production and efficiency of livestock rearing (Morris *et al*., 2012). One of the facets of precision livestock rearing is the incorporation of decision support systems that make use of models developed from data collected from specific production systems, which are used to simulate production scenarios and predict outcomes that will assist the producer in adapting their management strategies (Villeneuve *et al*., 2019).

To develop models which can be incorporated into such a system, one would first need to model the growth of the lambs. For an accurate growth model, the full growth curve of the lambs needs to be established from birth to their mature body weight in order to accurately predict the true inflection points of the curve, using longitudinal or continuous weight data collected throughout the growth period of lambs reared under optimal conditions (Fitzhugh, 1976). Modelling the growth of lambs reared under optimal conditions limits variation brought on by the environment and produces a smooth curve, with the same parameter values for the entire curve, which represents the growth potential of the lambs (Lewis *et al*., 2002). The growth model functions can then be differentiated in order to determine the change in growth rates of the growing lambs from birth to maturity, peaking at the point of inflection of the growth curve (Goshu & Koya, 2013). The growth models of the different breeds can then be used in order to assist in predicting body weights which will assist in establishing feeding strategies, as well as determine an optimal slaughter age based on growth characteristics (Hossein-Zadeh, 2015). With feeding costs making up ~70% of inputs in an intensive system (Lima *et al*., 2017), it is important to be able to predict feed intake of growing lambs. Knowledge of feed intake patterns is important for diet manipulation, predicting animal performance and controlling production systems (Illius *et al*., 2000). Feed intake is influenced by a number of animal as well as diet factors (Pulina *et al*., 2013) which all contribute to a mechanistic model which relies on empirical relationships (Illius *et al*., 2000). Therefore, the first step in modelling feed intake is to develop models based on the body weight of the lambs and then to later take the composition of the feed into account (Emmans, 1997). The body weights and feed intakes of lambs represent the main inputs used in a feedlot system in order to calculate profitability, however, an ideal slaughter weight must still be determined.

As the industry strives for uniformity and to meet target consumer specifications, in terms of lamb carcass fatness, more accurate measures are needed to predict final carcass merit (Hamlin *et al*., 1995). Conventional methods of determining the ideal point of slaughter for lambs include weighing, visual assessment and condition scoring, though, X-ray, video imaging and ultrasound technologies can be used to give a more accurate indication of expected carcass composition (Stanford *et al.,* 1998). Of these tools, the use of ultrasound scans is more commonly implemented to predict carcass composition from live weight measurements (Hopkins *et al.,* 1996; Silva *et al*., 2005; Grill *et al*., 2015). Measuring the subcutaneous fat depths of lambs allows the producer to select the optimal point of slaughter with respect to the carcass classification values in order to achieve a more desirable carcass composition (Andrade *et al*., 2017). The implementation of ultrasound technology to measure back-fat depths of lambs may not be feasible in many production systems. Therefore, by modelling the subcutaneous fat depth, measured using ultrasound scans, with body weight can be used for predicting the level of fat cover from the live weights of the growing lambs. Combining this information with growth and intake models proposed above will give an even more accurate description of the production characteristics and predict the ideal slaughter weight of feedlot lambs. By incorporating data on the product traits derived from sheep, namely: meat, wool and leather, and attributing economic values to these products will allow lamb producers, as well as processors, to make informed decisions on the marketing of the products from different breeds.

The aim of the studies presented in this dissertation is to develop models that can be used in a decision support system that encompasses the growth, feed intake,fat deposition and wool production characteristics of different South African sheep breeds. The studies also aim at providing a description of the production and carcass quality characteristics of premium lamb from various breeds as well as wool and sheepskin quality. This will then allow producers to run simulations in order to predict the optimal rearing times and ideal slaughter weights of lambs, as well as marketing channels for the end products, depending on economic conditions.

## References

Addah, W., Ayantunde, A., Okine, E.K., 2017. Effects of restricted feeding and re-alimentation of dietary protein or energy on compensatory growth of sheep. S. Afr. J. Anim. Sci., 47, 389-396.

Andrade, A.C.S., de Macedo, F.D.A.F., de Arruda Santos, G.R., de Oliveira Queiroz, L., Mora, N.H.A.P., Macedo, T.G., 2017. Regional composition of carcass and tissue composition of cuts from lambs slaughtered with different subcutaneous fat thicknesses. Semin-Ciênc. Agrár., 38, 2019-2028.

Bello, J.M., Mantecón, A.R., Rodriguez, M., Cuestas, R., Beltran, J.A., Gonzalez, J.M., 2016. Fattening lamb nutrition. Approaches and strategies in feedlot. Small Rumin. Res., 142, 78-82.

Brand, T.S. & Franck, F., 2000. Production responses of two genetic different types of Merino sheep subjected to different nutritional levels. Small Rumin. Res., 37, 85-91.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci., 47, 26-33.

Brand, T.S., Van Der Westhuizen, E.J., van Der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci., 48, 477-488.

Bruwer, G.G., Naude, R.T., Du Toit, M.M., Cloete, A., Vosloo, W.A., 1987. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 2. The use of fat measurements as predictors of carcase composition. S. Afr. J. Anim. Sci., 17, 85-89.

Cloete, S.W.P., Olivier, J.J., 2010. South African Industry. In: The International Sheep and Wool Handbook. Ed. Cottle, D.J., Nottingham University Press, Nottingham. England. pp. 95-112.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V., 2001. Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric., 41, 145-153.

Cloete, S.W.P., Snyman, M.A., Herselman, M.J., 2000. Productive performance of Dorper sheep. Small Rumin. Res., 36, 119-135.

Department of Agriculture, Forestry & Fisheries. 2019. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63.

(https://www.daff.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202019.pdf?timestamp=1568549611726 ).

Emmans, G.C., 1997. A method to predict the food intake of domestic animals from birth to maturity as a function of time. J. Theor. Biol., 186, 189-199.

FAOSTAT, 2019. http://www.fao.org/faostat/en/#data/RL (Accessed 18 October 2019).

Fitzhugh Jr, H. A., 1976. Analysis of growth curves and strategies for altering their shape. J. Anim. Sci., 42, 1036-1051.

Goshu, A.T., Koya, P.R., 2013. Derivation of inflection points of nonlinear regression curves-implications to statistics. AM. J. Theor. Appl. Stat., 2, 268-272.

Government Notice No. R. 863 of 1 September 2006. Agricultural product standards Act 119 of 1990. Regulations regarding the classification and marketing of meat in the Republic of South Africa.

Grill, L., Ringdorfer, F., Baumung, R., Fuerst-Waltl, B., 2015. Evaluation of ultrasound scanning to predict carcass composition of Austrian meat sheep. Small Rumin. Res., 123, 260–268.

Hamlin, K.E., Green, R.D., Cundiff, L.V., Wheeler, T.L., Dikeman, M.E., 1995. Real-time ultrasonic measurement of fat thickness and longissimus muscle area: II. Relationship between real-time ultrasound measures and carcass retail yield. J. Anim. Sci., 73, 1725-1734.

Hossein-Zadeh, N.G., 2015. Modeling the growth curve of Iranian Shall sheep using non-linear growth models. Small Rumin. Res., 130, 60-66.

Hopkins, D. L., Hall, D. G., Luff, A. F., 1996. Lamb carcass. 3. Describing changes in carcasses of growing lambs using real-time ultrasound and the use of these measurements for estimating the yield of saleable meat. Aust. J. Exp. Agric., 36, 37–43.

Illius, A.W., Jessop, N.S., Gill, M., 2000. Mathematical models of food intake and metabolism in ruminants, in: Cronjé P.B., (ed) Ruminant physiology, digestion, metabolism growth and reproduction (). CABI Publishing, Wallingford, UK, pp.21-40.

Kosulwat, S., Greenfield, H., James, J., 2003. Lipid composition of Australian retail lamb cuts with differing carcass classification characteristics. Meat Sci., 65, 1413-1420.

Lewis, R.M., Emmans, G.C., Dingwall, W.S., Simm, G., 2002. A description of the growth of sheep and its genetic analysis. Anim. Sci., 74, 51-62.

Lima, N.L.L., Ribeiro, C.R.D.F., Sá, H.C.M.D., Leopoldino-Júnior, I., Cavalcanti, L.F.L., Santana, R.A.V., Furusho-Garcia, I.F., Pereira, I.G., 2017. Economic analysis, performance, and feed efficiency in feedlot lambs. R. Bras. Zootec., 46, 821-829.

Milne, C., 2000. The history of the Dorper sheep. Small Rumin. Res., 36, 99-102.

Morris, J.E., Cronin, G.M., Bush, R.D., 2012. Improving sheep production and welfare in extensive systems through precision sheep management. Anim. Prod. Sci., 52, 665-670.

Peters, F.W., Kotze, A., Van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res., 90, 101-108.

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. R. Bras. Zootec., 42, 675-690.

Qwabe, S.O., van Marle-Köster, E., Visser, C., 2013. Genetic diversity and population structure of the endangered Namaqua Afrikaner sheep. Trop. Anim. Health Prod., 45, 511-516.

Raineri, C., Nunes, B.C.P., Gameiro, A.H., 2015. Technological characterization of sheep production systems in Brazil. Anim. Sci. J., *86*, 476-485.

Rust, J.M., Rust, T., 2013. Climate change and livestock production: A review with emphasis on Africa. S. Afr. J. Anim. Sci., 43, 255-267.

Sañudo, C., Alfonso, M., Sánchez, A., Delfa, R., Teixeira, A., 2000. Carcass and meat quality in light lambs from different fat classes in the EU carcass classification system. Meat Sci., 56, 89-94.

Silva, S.R., Gomes, M.J., Dias-da-Silva, A., Gil, L.F., Azevedo, J.M.T.D., 2005. Estimation in vivo of the body and carcass chemical composition of growing lambs by real-time ultrasonography. J. Anim. Sci., 83, 350–357.

Stanford, K., Jones, S.D.M., Price, M.A., 1998. Methods of predicting lamb carcass composition: A review. Small Rumin. Res., 29, 241-254.

Tainton N.M., 1988. A consideration of veld condition assessment techniques for commercial livestock production in South Africa, J. Grassl. Soc. S. Afric., 5, 76-79.

Villeneuve, E., Akle, A.A., Merlo, C., Masson, D., Terrasson, G., Llaria, A., 2019. Decision support in precision sheep farming. Proc. of the 2nd IFAC Conference on Cyber-Physical & Human-Systems, 51, 236-241.

Vorster, M., Botha, P., Hobson, F.O. 1983. The utilization of Karoo veld by livestock, Proc. Annual Congress of the Grassland Society of Southern Africa, 18, 35-39.

# Chapter 2 - Precision finishing of South African lambs in feedlots


## Abstract

In the intensification of sheep production systems, feedlot finishing plays a fundamental role in preparing lambs for slaughter, as well as relieving the grazing pressure on pasture. The profit margins in feedlot operations are often narrow and require the economics of scale to generate a sufficient income. In order to minimise expenses, intensive management and precision rearing of lambs to an ideal slaughter weight is needed to obtain premium carcass prices. The South African sheep industry is made up of wool, dual-purpose as well as meat type breeds, which also vary in terms of maturity. In order to implement precision finishing of South African lamb, a complete understanding of the growth, intake and fat deposition trends of growing lambs of different breed types is needed. This review outlines feedlot lamb production within the Southern African context for the major commercial breeds, while also providing insight in the considerations necessary to develop a decision support system for lamb rearing. Integrating such a decision support system into a lamb feedlot operation can then be used for precision finishing of lambs by predicting the optimal length of the feeding period and ideal slaughter weights of lambs.


**Keywords:** *Maturity types; Intensification; Premium lamb; Modelling*; *Decision support system*

## 2.1 Introduction

Feedlot finishing is used to add value to the carcass of a lamb with a poor conformation through intensive feeding of the live lamb to promote muscle tissue growth and fat deposition to obtain a more desirable meat product. Relative to European markets, the South African market generally calls for a heavier lamb (18-22 kg carcass *vs*. 10-13 kg carcass) with a greater meat yield (Alfonso *et al*., 2001; Schönfeldt *et al*., 2011; Bello *et al*., 2016). The South African industry produces approximately 177 000 tonnes of lamb and mutton per annum (DAFF, 2019), with increased pressure for farmers to increase production all the while flock numbers decrease. It is predicted that as a result of climate change, the occurrence of droughts will become more frequent, placing pressure on available resources and cause farmers to produce more efficiently (Meissner *et al*., 2013). As a result, farmers must intensify their operations in order to maintain production. The implementation of feedlot finishing of lambs does not only provide a method of fattening lambs in a more efficient manner, but also alleviates grazing pressure and improving the production output per hectare.

Increases in lamb meat prices in recent years (DAFF, 2019), and the incidence of droughts, have encouraged lamb producers to make use of feedlot systems in enhancing their income from lamb production. However, profit margins in a feedlotting enterprise remain relatively narrow and are susceptible to fluctuations in the prices of commodities. The economics of scale as well as careful management and planning are thus necessary to ensure that a sustainable income is generated from such an operation. The South African sheep industry is also made up of a number of breeds suited to different production systems, with breeds varying in their capacities for growth and meat/wool production. Therefore, in order to sustain optimal production, information on the production characteristics of lambs from the various breeds is required.

In an era of great technological advancement, opportunities arise to incorporate technology to assist farmers in livestock rearing (Morris *et al*., 2012). The ability to predict the performance of lambs entering a feedlot would allow producers the opportunity to adapt management strategies to ensure sustainable production and guarantee profitability. This review aims at describing the South African lamb feedlotting industry and highlighting the considerations necessary to implement precision lamb rearing and predict production performance of different lamb breeds.

## 2.2 Background of sheep production systems

Of the agricultural land available in South Africa, only 12.5% is considered to be arable land for crop cultivation (FAOSTAT, 2019). This means that the remaining agricultural land can only be utilised for animal production. Large regions of the South African country consist of arid and semi-arid biomes which can only be utilised for sheep production systems (Brand, 2000). The ability of sheep to utilise poor quality roughage and to select more palatable plant matter, allow them to survive and produce under these conditions. As a result of recent droughts experienced throughout the country, livestock numbers have experienced a decrease, with the national sheep flock currently being estimated to consist of 19.9 million head of sheep (DAFF, 2019). Sheep are reared in South Africa for both wool and meat production, with lamb meat production contributing a greater portion to the overall income while income from wool fluctuates (Cloete *et al.,* 2003). The sheep industry currently produces about 177 000 tonnes of meat and 48 200 tonnes of wool per annum (DAFF, 2019). The breeds utilised in sheep production systems range from wool type, dual-purpose, meat-type as well as indigenous breeds, depending on the type of production and region.

Due to increased pressure to improve production and enhance profitability, many sheep production systems are undergoing intensification through strategic supplementation and breeding in order to increase the production per hectare. Other intensive management principles that are being included in lamb production are the incorporation of accelerated lambing systems (Lewis *et al*., 1996), lambing pens (Watson *et al*., 1968), creep feeding (Terblanche *et al*., 2012) as well as feedlot finishing (Brand *et al*., 2017). This high level of nutrition and value adding of the lambs ensures higher growth rates with improved feeding efficiency so as to prepare the lambs for the market as soon as possible. This allows for a greater number of lambs, as well as parent stock, to be reared and so increasing the production capacity per hectare. As most production systems in South Africa herd sheep on extensive grazing, fodder flow throughout the year is of great importance to maintain flock numbers. Forage resources in the semi-arid regions, particularly in the Karoo biomes, where sheep production takes place is limited in availability and quality; with much of the natural veld being overstocked, leading to a long-term reduction in the grazing capacity (Vorster *et al*., 1983; Tainton, 1988). It is therefore important that the number of stock units be controlled to meet the grazing capacity. Early weaning of lambs (~100 days of age) and rearing them for market in feedlots, allows a greater portion of grazing land to be available to the breeding ewes. Feedlot finishing systems suit the South African sheep industry in helping to alleviate grazing pressure of the veld which undergoes seasonal variability in terms of quantity and quality. This becomes of greater importance as climatic conditions become hotter and drier which influences pasture composition and quality (Rust & Rust, 2013).

Upon weaning, producers have the option of rearing their lambs on pasture or cereal stubble or feed the lambs concentrate diets in feedlots. Pasture finishing of lambs is, however, limited by abundance of plant material and the carrying capacity of the veld to sustain the growth of the lambs as well as provision of adequate feed for the breeding ewes. Effective pasture finishing of lambs can be achieved with strategic supplementation of energy and protein licks in order to ensure good growth rates and limit pasture degradation (Ben Salem & Nefzaoui, 2003). Therefore, feedlot finishing of lambs is a more popular option in ensuring market ready lambs in a shorter rearing period. Alternatively, lamb producers, who might not have the facilities or nutritional resources to rear the lambs to a desirable slaughter weight, can market their weaner lambs to commercial feedlots. These commercial feedlots finish lambs on a large scale under conditions to optimise growth and efficiency. Often, these feedlots will be integrated with an abattoir in order to take advantage of the slaughter lamb value chain.

## 2.3 Feedlot finishing of lambs

Profitability is the main driver in a feedlot finishing operation. The main factors affecting feedlot profit margins include the buying price of the store lambs, the price of meat produced, along with the dressing percentage of the carcass, the price of feed consumed by the animal as well as the efficiency of growth achieved (Lima *et al.*, 2017). The practice of feedlotting is summarised as the practice of purchasing of young, weaner animals, improving their market value through intensive feeding and management to produce a carcass that meets the market specifications. The practice of using weaner lambs in such a system is to take advantage of the high growth rates that lambs exhibit soon after weaning, and so ensure feeding efficiency before lambs deposit high levels of fat. This also takes advantage of complimentary growth in lambs that did not receive adequate nutrition for growth prior to weaning (Addah *et al.*, 2017). The first capital input in a feedlot is the value of the store lamb at weaning, which is determined by the live weight of the lamb at this point. Live weights of lambs at weaning can vary between 25-35 kg, depending on the breed as well as age at weaning that the lambs are subjected to in the production system. Lambs are typically weaned around 100 days of age (Neser *et al.*, 2000), though when weaning according to a predetermined body weight, lambs may be weaned at an earlier age. The length of the feeding period to finish the lambs is determined by the desired end weight and subcutaneous fat cover of the lamb along with the growth rate of the lambs. Many producers either work on rearing their lambs to a fixed predetermined slaughter weight or for a fixed duration of the feeding period (4-6 weeks). Brand *et al.* (2018) demonstrated the ideal slaughter weights for South African lambs as 42.7 kg for both Merino and South African Mutton Merino lambs and 36.0 kg for Dorper lambs. According to Brand *et al.* (2017), this would equate to rearing periods of 49 days for Merino, 36 days for South African Mutton Merino and 13 days for Dorper lambs. Due to the differences in maturity for the different breeds, consideration is needed in determining the slaughter weight of a specific breed in order to prevent carcasses being classed as over-fat and so reducing the value of the carcass.

The next input includes the amount of feed that will be required to rear the lamb from the initial weight to the desired weight as well as the cost of the feed required to rear the lambs. Knowledge of daily feed intake and growth rate are then needed to determine the length of the feeding period as well as total amount of feed required. In order to ensure optimal growth, feedlot lambs are provided a concentrated ration that is high in energy and protein in order to match the requirements of the growing lambs. The typical nutritional requirements for growing lambs are outlined in Table 2.1. The body weight and growth rate of lambs have previously been used to estimate the energy, protein and macro-mineral requirements for growth along with the proposed level of intake (National Research Council, 2017). Grain concentrate mixes as well as silages are typically used in feedlot systems (Van de Vyver *et al.*, 2013), depending on the price and availability of raw materials which can be accessed. As nutrition in an intensive feeding system accounts for approximately 70% of the capital inputs (Lima *et al.*, 2017); least cost diets must be formulated in order to reduce feeding costs, while still maintaining acceptable growth rates and health of the animals. Pelleting of the feedlot ration is often also applied in order to prevent feed sorting and selection and so improve feed utilisation, while also improving feed intake and minimising wastage (Greenhalgh & Reid, 1973).

In order to meet the energy demands of the lambs for growth, feed ingredients with high starch, and relatively low fibre, are included in the feedlot diets. Starch, being highly fermentable in the rumen, results in an accumulation of lactic acid which reduces the pH causing ruminal acidosis. Upon introduction to the feedlot diet, lambs are susceptible to developing acidosis and must therefore be gradually introduced to the feedlot ration so as to adapt the rumen microbiota to the new diet (Kleen *et al*., 2003). Nutritionists often include a probiotic, yeast or ionophore along with buffers in order to assist with the adaptation of the rumen microbial population in order to reduce the adaptation period and so improve growth of the lambs (Pienaar *et al*., 2012). In many feedlots this adaptation period is well incorporated into the feeding regime, by initially feeding the lambs a starter diet for a week, to aid in transitioning the lambs from a forage based to a high concentrate diet. The lambs are then provided the feedlot grower diet, which contains sufficient energy and protein (Table 2.1) to promote muscle tissue growth and fat deposition after the maximum protein deposition rate has been reached (Johnson *et al*., 2012). This grower feeding phase lasts for three to five weeks after the adaptation period, until the lambs have attained a desirable slaughter weight.

**Table 2.1** The nutritional requirements of growing lambs adapted from the National Research Council (2017).

| Body weight (kg) | ADG (g/day) | Daily feed intake (kg/day) | Total digestible nutrients (kg/day) | Metabolisable energy (MJ/day) | Crude protein[a] (g/day) | Rumen undegradable protein [a] (g/day) | Ca (g/day) | P (g/day) |
|---|---|---|---|---|---|---|---|---|
| 20 | 200 | 0.83 | 0.66 | 22.0 | 101 | 40.4 | 3.4 | 2.7 |
| | 300 | 1.20 | 0.95 | 31.7 | 142 | 56.8 | 4.9 | 4.0 |
| 30 | 200 | 1.20 | 0.79 | 26.4 | 119 | 47.6 | 3.7 | 3.0 |
| | 300 | 1.25 | 0.99 | 32.9 | 148 | 59.2 | 4.9 | 4.0 |
| | 400 | 1.62 | 1.28 | 42.7 | 189 | 75.6 | 6.4 | 5.4 |
| 40 | 250 | 1.50 | 1.00 | 33.2 | 148 | 59.2 | 4.6 | 3.8 |
| | 300 | 1.29 | 1.02 | 34.0 | 153 | 61.2 | 5.0 | 4.1 |
| | 400 | 1.66 | 1.32 | 43.9 | 195 | 78.0 | 6.4 | 5.4 |

[a] Rumen undegradable protein requirements calculated as 40% of crude protein requirements.

In an intensive operation such as a sheep feedlot, it is important to consider measures of efficiency in order to gauge management. Zootechnical indices relating to feed intake, growth rate and utilisation of feed for growth are important for measuring efficiency and sustainability in a production system (Bello *et al*., 2016). The most popular indices used in finishing systems include feed intake, average daily gain (ADG) and feed conversion ratio (FCR), which is defined as the amount of feed consumed to gain a unit of body weight. The level of feed intake, as well as the nutritional composition of the diet, affects these measures; as feed intake is a major factor influencing the amount of nutrients available to the lamb to realise its growth potential. In finishing lambs, it is sought to increase the quantity feed consumed by the lamb so as to provide the nutrients to increase the growth rate of the lamb, while at the same time not reducing feeding efficiency. Reduced nutrient utilisation is undesirable as it results in an increase in the length of the rearing period and thus an increase in the feeding costs of the system. Improvements in feed efficiency not only benefit the profitability of the production system, but can be used as a strategy to reduce greenhouse gas emissions (Marino *et al.*, 2016). For profitable production, producers often aim for an ADG of 300 g/day and FCR of 5.0 kg feed/ kg weight gain, depending on the breeds and type of feed used in the finishing system. Individual growth rates greater than 350 g/day and feed conversion rates lower than 4.5 feed/ kg weight gain during the finishing period are regarded as exceptional performances (Coetzee, 2004).

Whilst high growth rates and feeding efficiencies can be associated with lean tissue growth, increased fat deposition is costly in terms of energy utilisation from the feed for maintenance, and results in relatively lower daily gains and an unfavourable FCR (Johnson *et al.,* 2012). Fat deposition, on the other hand, is required in the process of adding value to the lamb carcass. The growth of lean tissue along with the accretion of fat in the subcutaneous depot increases the composition of the carcass as well as the dressing out percentage of the carcass, as the subcutaneous fat is regarded as part of the carcass (Snyman & Herselman, 2005). An increase in subcutaneous fat is therefore associated with a greater carcass yield and so higher income per head slaughtered (Brand *et al.*, 2017). Feedlots aim to produce lambs with an optimal fat cover which meets the market’s specifications according to carcass classification and grading systems so as to obtain premium prices for lamb carcasses. The significance of the optimal fat cover is to provide satisfactory eating quality characteristics with the meat, while at the same time avoiding excessive fat consumption which may be associated with cardiovascular health risks (Webb & O’Neill, 2008). Feedlot operators therefore aim for the optimal carcass fat cover to prevent price deductions as result of over-fatness of the carcass, which is also coupled with reduced feeding efficiency, further impacting profit margins. Profit margins per individual animal are generally low; therefore, economics of scale are required to make the feedlot a competitive enterprise, with the profits being shared from a large stock of animals.

As a result, the narrow margins influencing profitability, intensive management is required in order to enhance efficiency. It is therefore essential that lambs are reared under optimal conditions to attain maximum growth rates in order to reduce the rearing time. The maturity and fat deposition characteristics of lambs of different breeds must be taken into consideration in determining an optimal slaughter weight. The South African industry is made up of a number of breeds that have been selected to varying degrees for either wool or meat production (Cloete *et al.,* 2012; Cloete *et al.*, 2014). Nonetheless, favourable meat prices for lamb and limited grazing compel producers to produce lambs for slaughter, regardless of breed. For efficient management and finishing of slaughter lambs, knowledge of the production characteristics of different sheep breeds is required.

## 2.4 Major South African sheep breeds

The sheep sector in South Africa has realised a steady decline in the number of sheep produced, with the number of sheep in commercial systems being estimated at 19.8 million head in 2018 (DAFF, 2019). With the decline in numbers, it is essential that lamb production intensifies in order to meet the demands of the industry. For this to be achieved, a full understanding of the breeds that make up the small stock sector is required. The South African industry is made up of a range of breeds that are suited either to wool and/or meat production. According to weaning weights collected under the National Small Stock Improvement Scheme (Cloete *et al*., 2014) wool breeds (Merino, Dohne Merino and South African Mutton Merino) contribute about 68% of the records, while hair meat breeds (Dorper, Meatmaster and Van Rooy) contribute 22% and terminal sire breeds (Dormer, Il de France, Sufflok and Merino landsheep) make up the final 10%. Other breeds that contribute to the South African flock, to a lesser extent, include fat-rumped Persian sheep, as well as fat-tailed Damara, Zulu (Nguni), Pedi, Swazi and Afrikaner type breeds (Soma *et al*., 2012). Karakul sheep are also herded for Karakul pelt production, although this breed only accounts for ~0.1% of commercial flock numbers (DAFF, 2019). The various South African sheep breeds have been shown to be genetically distinct, even while common ancestral breeds were involved in the development of the different sheep breeds (Sandenbergh *et al*., 2018).

Two ancestral breeds are responsible for the development of the wool breeds currently found in South Africa. The Merino breed was introduced to South Africa from Spain in the 18$^{th}$ century and has since been popular as a wool producing breed; while after the decline in wool price in the 1990s, breeding strategies applied to Merino have changed to improve overall profitability (Cloete *et al*., 2007). The German Mutton Merino was first imported into South Africa in 1932 and served as the basis for the establishment of the South African Mutton Merino (SAMM) (Cloete *et al*., 2004a) and the Dohne Merino, after crossbreeding with the Merino to develop a more versatile genotype (Van Wyk *et al*., 2008). The Dohne Merino and SAMM breeds are both considered to be dual-purpose breeds rather than primarily wool producing breeds. The Dohne Merino, though, is more orientated towards wool production than the SAMM and produces a heavier fleece with a finer fibre diameter similar to that of Merino wool (<21 µm) (Cloete *et al*., 2001). The SAMM on the other hand, is more orientated towards meat production with lambs; weaning heavier lambs that present high growth rates in the feedlot (up to 375 g/day) (Cloete *et al*., 2001; Brand *et al*., 2017). The German Mutton Merino was also involved in the development of the Dormer breed, when ewes were crossed with Dorset-horn rams in the 1940s in order to develop a terminal sire breed (Van Wyk *et al*., 2003). The Dormer exhibits high growth rates and is used to improve the growth and conformation of lambs in terminal breeding systems (Cloete *et al*., 2003). Other terminal sire breeds (Il de France, Merino Landsheep and Suffolk) were introduced from Europe, although they are not as popular as the Dormer in South African crossbreeding systems.

The Dorset-horn was also involved in the development of the Dorper breed when the need arose to produce a meat type sheep breed that was capable of surviving the more harsh South African conditions (Milne, 2000). The Dorper was then developed from crosses of Dorset-horns with Black-headed Persian sheep with white varieties (White Dorper) also being bred. The Dorper is a non-wool breed that exhibits good growth characteristics with a well-rounded conformation; it is also known as an early maturing breed and must therefore be slaughtered at an earlier stage to prevent carcasses from being overfat (Cloete *et al*., 2000; Brand *et al*., 2018). The Meatmaster is a fairly modern synthetic composite that is well suited to meat production under harsh conditions. The Meatmaster was bred using the fat-tailed Damara as a maternal line and crossing with Il de France, Dorper and SAMM breeds in order to improve conformation and carcass quality, with later crosses with Van Rooy sheep being incorporated to improve coat covering (Peters *et al*., 2010). Like the Dorper and Damara, the Meatmaster is a hair sheep breed that is also characterised by the fat tail which is not docked. Many of the indigenous breeds fall within the fat-tailed category, with the large amounts of fat stored in the tail or rump region which allows the breeds to be more resilient to challenging environments (Mohapatra & Shinde, 2018). The Namaqua Afrikaner is such an indigenous fat-tailed breed, which migrated with the Khoisan (Qwabe *et al*., 2013). Although the Namaqua Afrikaner breed is not as popular as the breeds previously mentioned and has not undergone selection for improved production characteristics, it still is an important breed in extensive smallholder production systems and possesses the potential for crossbreeding to improve the robustness of a breed (Qwabe *et al*., 2013; Soma *et al*., 2012). An example of this crossbreeding is the development of the Afrino, composed of ¼ Merino, ¼ Ronderib Afrikaner and ½ SAMM, selecting for a hardy white-wooled breed (Schoeman *et al*., 2010).

### 2.4.1 Growth and maturity types

The growth of an animal incorporates the increase in size and mass of the individual, as well as the differentiation and development of different body tissues. Plotting cumulative weight gain against time of an individual, from birth to maturity, produces a sigmoidal growth curve. This curve is characterised by an initial lag phase, followed by a self-accelerating growth phase then a post-pubertal decelerating phase as growth plateaus as the individual nears its mature weight. As the animal grows, bone tissues mature relatively earlier than other tissues, followed by lean muscle growth; fat tissues are later maturing and develop at a higher rate after the pubertal phase (Butterfield, 1988; Owens *et al*., 1993). Differences in the development of the various body fat depots, namely, abdominal, kidney and channel fat, subcutaneous, tail as well as inter and intramuscular fat are observed, with differences in partitioning being observed in different breeds (Kempster, 1981: Negussie *et al*., 2003; Brand *et al*., 2018). The mature weight of an animal is regarded as the point at which maximum muscle mass has been reached (Owens *et al*., 1993). Lambs therefore grow rapidly during the first year of birth, particularly before puberty, after which the body weights tend to stabilise around the mature or asymptotic weight (Najari *et al*., 2007).

At this mature weight, the animal reaches its physiological limits to growth, which are also associated with increased maintenance requirements of body tissues (Webb & Casey, 2010). In young animals, the relative proportion of muscle is higher than that of fat in the body (Owens *et al*., 1993). As the young animal grows, the amount of energy required in order to synthesise and deposit protein in muscle is higher than that of fat, while the energy density of fat is greater than that of protein (Webster, 1980). While nutrition is not limited, tissue growth will continue primarily in muscle and then adipose tissues. Protein accretion increases with available nutrients until a maximum protein accretion rate is reached and excess nutrients are deposited as fat (Gerrits *et al*., 1996). As the adipose tissues mature and higher levels of fat are deposited, the maintenance requirements of the animal increases; due to the higher energy density of fat tissue more energy is required to maintain body fat than to maintain less dense muscle (Lawrence *et al*., 2012). Growth rate of the animal then decreases and feeding efficiency is reduced as the animal cannot consume sufficient quantities to maintain the high growth rates. After the asymptotic weight has then been attained, any fluctuations in weight may be associated with the nutritional or production status of the animal (Bathaei & Leroy, 1996).

With the different selection pressures being applied to the different breeds, it is expected that each breed will vary in its growth and fat deposition characteristics. The mature body weight of a sheep is related to its potential growth rate, with larger animals presenting higher growth rates and attaining physiological maturity at a later stage than smaller breeds (Butterfield, 1988; Owens *et al*., 1993). Rams have a heavier mature weight, and exhibit higher growth rates than ewes, within the same breed, while also depositing fat at a later stage. The effect of castration (prior to puberty) then reduces the growth rate of ram lambs and also results in earlier fat deposition (Field *et al*., 1993), which also indicates a reduction in mature weight. Finlayson *et al.* (1995) presented estimates for the mature empty body weights of different breed types (Table 2.2), though these may not necessarily be applicable to all of the South African breeds. Cloete *et al*. (2012) noted slaughter weights of 20-month-old sheep maintained on pasture for Merino (40.8 kg), Dohne Merino (56.0 kg), SAMM (63.2 kg) and Dormer (61.4 kg) breeds, with rams being ~20% heavier than ewes. However, it must be noted that the sheep in their study were maintained on pasture and not allowed to grow according to their genetic potential. Similar to Finlayson *et al*. (1995), it can be seen that the weights of wool (Merino) breeds are lighter than the corresponding dual-purpose breeds and subsequently meat breeds. Although, the SAMM breed tends to resemble the terminal sire Dormer breed with respect to body weight (Cloete *et al*., 2004b; Cloete *et al*., 2012).

**Table 2.2**. Maximum empty body weights for different sheep breed types (Finlayson *et al.,* 1995).

| **Breed type** | **Maximum empty body weights (kg)** | | |
|---|---|---|---|
| | **Rams** | **Wethers** | **Ewes** |
| Meat | 85.8 | 80.0 | 66.7 |
| Wool | 76.1 | 72.0 | 60.2 |
| Dual-purpose | 81.5 | 76.0 | 63.7 |

With regard to maturity differences, the Dorper breed is widely renowned as an early maturing breed that tends to deposit higher levels of fat at an earlier stage than most breeds (Cloete *et al*., 2000; Brand *et al*., 2018). The Dorper was bred from Black-headed Persian sheep, a fat-rumped breed, and Dorset sheep in order to ensure improved meat production and survival under arid conditions (Cloete & de Villiers, 1987). Tropical breeds show enhanced partitioning of fat, particularly in internal and tail or rump depots, that can be mobilised during periods of nutritional fluctuations; which makes these breeds more resilient to arid conditions (Ermias *et al*., 2002). Therefore fat-tailed breeds such as the Damara as well as Meatmaster and Namaqua Afrikaner breeds show early maturing fat deposition characteristics, particularly in the tail-rump region (Tshabalala *et al*., 2003; Burger *et al*., 2013). These fat-tailed breeds are also associated with low mature body weights (Mohapatra & Shinde, 2018), confirming their early maturing status. Wool type breeds are on the other hand considered to be later maturing, though wool breeds with lower mature weights would be expected to be early maturing relative to larger dual-purpose breeds at the same body weight. South African Mutton Merino and Dormer sheep that are regarded as late maturing, with heavier mature weights, also differ in terms of fat deposition with Dormer lambs presenting higher levels of body fat than SAMM lambs at a given body weight (Cloete *et al*., 2004b).

Maturity and fat deposition characteristics of different sheep breeds are important to take into consideration in a lamb finishing enterprise as they directly influence the profitability of the system. While feeding for prolonged periods, the increased fat deposition increases the maintenance requirements of the animal and so result in a reduction of feeding efficiency of meat type breeds (Brand *et al*., 2017), increasing production costs. At slaughter, the abundance of carcass fat influences the classification and value of a carcass, while higher levels of subcutaneous fat also increase the yield of the carcass. However, excess subcutaneous fat must be trimmed in order to meet consumer specifications (Strydom *et al*., 2009), and so the value of the carcass is lowered. Internal fat depots may not necessarily influence carcass value; however, as these fat stores are removed during slaughter, they affect the slaughter yield. When expressing feeding efficiency with respect to carcass yield, the removal of excess subcutaneous, abdominal and kidney fat negatively influences the feed conversion ratio of the carcass produced (kg feed consumed/kg carcass weight). As a result, early maturing breeds are slaughtered at lower live weights so as to produce carcasses with a uniform degree of fatness as later maturing breeds, and so prevent deductions in carcass value due to excessive fatness (Brand *et al*., 2018).

## 2.5 Producing premium lamb

South African lamb meat prices have increased considerably over the last decade, making it favourable for producers to market slaughter lambs (Figure 2.1). While sheep numbers have decreased through the years, there is a sustained demand for lamb meat accounting for the increase in meat price. In recent years, the sharp increases in lamb meat price can be attributed to the *el niño* drought experienced during these years which resulted in many farmers having to buy in feed to rear their animals. In order to ensure the supply of lamb meat, meat prices have to be adjusted accordingly to the grain prices so as to allow producers to still rear lambs in a profitable manner. Lamb meat prices also tend to fluctuate throughout the year, with respect to the supply and demand for meat, with demand for lamb increasing particularly around cultural or religious festivals (Andargachew & Brokken, 1993).

Feeding costs in an intensive lamb rearing system can represent up to 70% of the inputs in a feedlot system (Lima *et al*., 2017). While the initial cost of the store lamb also represents a major portion of the input costs. Even when farmers opt to fatten their own lambs, rather than to market them to feedlots after weaning, they need to consider the initial value of the lamb at weaning in order to determine profitability. At auctions, feedlot operators purchase store lambs, per kilogram live weight, and after feeding the lambs in order to add value to the carcass, market the lambs at the current meat price (per kilogram carcass weight). The average value of a lamb at weaning (per kilogram live weight) obtained at auctions and contractors is approximately 51.6% of that of the lamb meat price (Red Meat Producers Organisation, 2019). Although, this ratio between the store lamb price and lamb meat price is subject to fluctuate throughout the year according to the supply and demand of lambs. When this initial value of the lamb at weaning is incorporated into the financial model of the feeding system, the relative contribution of feeding costs is greatly reduced from 70% to 20-30% of the inputs. However, grain and feed prices greatly influence the profit margins of rearing feedlot lambs. Other management costs that need to be taken into consideration are associated with veterinary, labour, transport and infrastructure maintenance costs. These costs are generally fixed and can be reduced with the economics of scale to spread the costs over a larger number of animals in the system. The longer rearing periods of later maturing breeds allow for greater gains and a larger carcass and so greater profit margins (De Bruyn, 1991). As a result, feedlots prefer not to rear early maturing breeds, such as Dorper sheep, which have a shorter rearing time to a desired slaughter weight.

Taking these financial inputs into account it is evident that profit margins for rearing lambs are fairly narrow. However, the slaughter value of a lamb at weaning is considerably lower than the store lamb value. This is because the smaller carcass of the weaner lamb does not meet the requirements of the consumer market in terms of conformation as well as muscle and tissue composition. Therefore, in order to generate profits from lamb production, value must be added to the carcass in the form of tissue growth to obtain a more desirable product with a higher economic value.

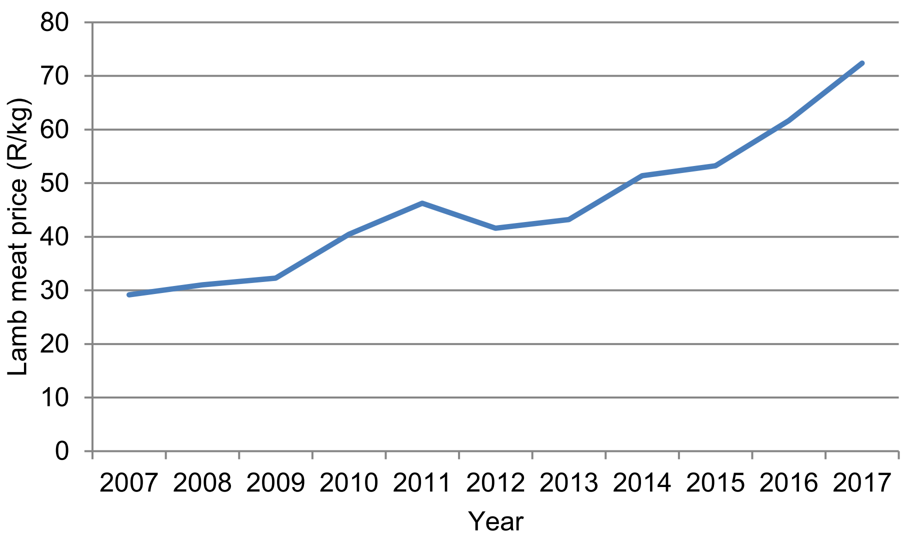


**Figure 2.1** Yearly average South African lamb meat price (R/kg) obtained at slaughter from 2007- 2017 (adapted from DAFF, 2019).

South African lamb carcasses are classed according to the South African red meat classification system according to age and fat cover (Government Notice No. R863, 2006). Initially, the system was developed in order to grade carcasses according to quality and value according to minimum prices for superior or lesser grades; the classification system was then introduced to describe carcasses in terms of physical or compositional qualities (Webb, 2015). Sheep carcasses are then classified according to age (based on dentition), degree of fatness and carcass conformation (Table 2.3). The descriptor of age is used to give an indication of tenderness, with meat from older animals having lower collagen solubility, resulting in tougher meat (Bruwer *et al*., 1987a). Fatness classes are used to give an indication of intrinsic quality cues relating to wholesomeness, juiciness and flavour (Bruwer *et al*., 1987a) as well as to give an indication of the carcass composition (Bruwer *et al*., 1987b). Visual appraisal of conformation of the carcass on the other hand does not give an accurate indication of carcass composition compared with subcutaneous fat measurements (Bruwer *et al*., 1987c). The conformation score, along with carcass weight, may thus give an indication of the size of the retail cuts, however, on its own does not provide sufficient information and so is not typically used in determination of carcass value.

**Table 2.3.** Guidelines for the classification of lamb/mutton carcasses according to age, degree of fatness and conformation (Government Notice No. R863, 2006).

| Descriptor | Classification | Guideline | Identifier |
|---|---|---|---|
| Animal age | A | No permanent incisors | Roller mark with purple ink. |
| | AB | At least one, but no more than two permanent incisors | Roller mark with green ink. |
| | B | At least three, but no more than six permanent incisors | Roller mark with brown ink. |
| | C | More than six permanent incisors | Roller mark with red ink. |
| Carcass fatness* | 0 | No fat, 0mm (<1.0% subcutaneous fat) | Fat class indicated along with age roller mark. |
| | 1 | Very lean, <1mm (1.0-5.6% subcutaneous fat) | |
| | 2 | Lean, 1-4mm (5.6-8.6% subcutaneous fat) | |
| | 3 | Medium, 4-7mm (8.6-11.6% subcutaneous fat) | |
| | 4 | Fat, 7-9mm (11.6-14.6% subcutaneous fat) | |
| | 5 | Slightly overfat, 9-11mm (14.6-17.6% subcutaneous fat) | |
| | 6 | Excessively overfat, >11mm, (>17.6% subcutaneous fat) | |
| Carcass conformation | 1 | Very flat | Stamp with conformation score on side of carcass. |
| | 2 | Flat | |
| | 3 | Medium | |
| | 4 | Round | |
| | 5 | Very round | |

* Subcutaneous fat measured between the third and fourth lumbar vertebrae, 25 mm from the midline of the carcass.

South African lamb and mutton production is estimated at more than 170 000 tonnes of meat annually (DAFF, 2019). According to the slaughter statistics collected weekly from registered abattoirs between 2016-2018 (Red Meat Producers Organisation, 2019), trends depicted in Table 2.4 show that the majority of lambs slaughtered are classed as A2 (~72.4%). This is to meet the consumer demands for lean lamb meat that still has sufficient fat to give desired eating quality attributes. Lamb carcasses with a medium fat cover (A3) make up ~14.4% of the population slaughtered. Less than 2% of lambs slaughtered consist of two-tooth yearling lambs (AB carcasses) which are mostly from slower growing Merino lambs reared on pasture that are also shorn before slaughter to obtain an income from the fleece as well. While meat from lamb is deemed to have superior eating quality characteristics, meat from yearlings is still deemed to be acceptable by Australian consumers with age having a small impact (Pannier *et al*., 2019). The South African market, alternatively, still regards the differences in eating quality of lambs and yearlings to be distinct, with hindquarters and loins of class AB carcasses still being deemed acceptable, with more enhanced differences being observed with mutton (Schönfeldt *et al*., 1993; Davel *et al*., 2003). Typically during the year, when there is a high demand for lamb, carcasses classed as A2 or A3 are marketed at the same price, however, when there is an abundance of lamb, differentiation of the meat price occurs with the A2 class receiving a higher price. Similar to the findings of Strydom *et al*. (2009), the carcass weights increase with the fat class (0-4), illustrating the value adding of the carcass in terms of tissue growth. Although, carcasses fatter than fat class 3 experience a penalisation in price due to necessary trimming of excess fat (Strydom *et al*., 2009). This reduction in meat price, along with costs of rearing the lamb to this degree of fatness greatly influences profit margins and sustainability of feeding lambs (Brand *et al.,* 2018).

**Table 2.4.** Average slaughter statistics of different South African lamb classes collected from registered abattoirs for years 2016-2018 (adapted from Red Meat Producers Organisation, 2019).

| Lamb carcass classification | Percentage of numbers slaughtered (%) | Average carcass weight (kg) | Average price index relative to A0[a] | Average carcass value index relative to A0[b] |
|---|---|---|---|---|
| A0 | 1.2 | 13.70 | 1.00 | 1.00 |
| A1 | 6.4 | 16.92 | 1.25 | 1.56 |
| A2 | 72.4 | 20.67 | 1.28 | 1.97 |
| A3 | 14.4 | 22.84 | 1.27 | 2.16 |
| A4 | 2.6 | 23.57 | 1.11 | 1.95 |
| A5 | 0.5 | 23.50 | 1.00 | 1.74 |
| A6 | 0.7 | 22.61 | 0.99 | 1.65 |
| AB2 | 1.4 | 22.32 | 1.11 | 1.82 |
| AB3 | 0.3 | 24.46 | 1.07 | 1.93 |

[a] Index calculated as average meat price of class expressed relative to meat price for A0 carcasses.
[b] Index calculated as average meat price multiplied by average carcass weight expressed relative to value for A0 carcasses.
(source: https://rpo.co.za/information-centre/industry-information/slaughtering-statistics/ )

When determining the overall value of a lamb carcass, by combining the meat price with the average carcass weight, it is seen that A3 lamb carcasses have the highest relative value followed by A2 and A4 carcasses (Table 2.4). However, it must be remembered that when there is a large supply of lambs, A2 carcasses will be given the premium prices, while the price of A3 lamb will decrease accordingly. In order to determine if it is profitable to market fatter lambs with a heavier carcass, the production costs of rearing the lambs for a longer period need to be taken into account. The type of breed being reared in the feedlot must also be taken into consideration with respect to the growth and maturation aspects of the breed. As breeds differ in their onset of maturity and fat deposition, the carcass weights of different breeds will vary at a given degree of fatness (Wood & MacFie, 1980). Therefore, early maturing breeds will have to be slaughtered at relatively lighter slaughter weights in order to achieve the same classification as later maturing breeds with the same level of carcass fat (Brand *et al*., 2017). Therefore, careful specific management is required in preparing lambs to be slaughter ready in order to achieve maximum profit margins.

## 2.6 Incorporating modern technology in lamb finishing systems

It is evident from the narrow profit margins involved in finishing lambs for slaughter that two concepts are necessary in order to ensure profitability of the system. The first is linked to the economics of scale, in order to spread the fixed and operational costs across a larger group of animals so as to reduce the input costs per head. Each operation is unique with respect to the resources available to it, and so the optimal number lambs that can be reared in the system depend on the limiting resources in terms of infrastructure, labour and feed raw materials. The second concept is that optimisation of the production system is required in order to enhance efficiency, limit wastage and ensure that a carcass product of uniform quality can be achieved in the shortest time possible so as to increase the number of cycles that can be reared to gain maximum profitability. This necessitates intensive management and the use of technology to assist in monitoring and decision-making processes.

The last three to four decades have been described as an era of rapid technological advancement in livestock production (Delgado *et al*., 1999). Aside from the progress in animal breeding to improve growth, production efficiency and reproduction using various selection toolkits; other technologies to improve management have led to improvements in animal production. With respect to feedlot finishing, the development of computer software to enable the formulation of balanced least cost diets was key in lowering production costs (Scott & Broadbent, 1972). The use of feed formulation software is then further complimented by updating models to more accurately predict the requirements of sheep for maintenance and growth so as to also predict the production response of the formulated ration (Tedeschi *et al.,* 2010). Further developments in terms of nutrition of feedlot lambs include the incorporation of various ionophores (Price *et al*., 2009) or beta-adrenergic agonists (such as Zilpaterol hydrochloride) in the feed, sometimes in conjunction with growth stimulants in order to increase growth rates and improve feeding efficiency (Webb *et al*., 2018). The inclusion of beta-adrenergic agonists in feedlot lamb diets has in some studies influenced the shear-force (increased the toughness) of the meat (Webb *et al*., 2018) while other studies did not show any differences in physical meat quality traits (Brand *et al*., 2013).

Apart from managing the diets of feedlot lambs for optimal growth and efficiency, intensification of production requires close monitoring of animal performance and welfare. The use of radio frequency identification (RFID) ear tags have been implemented in order improve accuracy of record keeping as well as to reduce labour time in handling of higher volumes of lambs (Morris *et al*., 2012). The use of RFID allows for ease of identification during weighing and drafting as well as distinguishing certain individuals that are either regarded as slow-growers or market ready lambs, by monitoring their growth (Brown *et al*., 2015). The use of RFID or accelerometer ear tags can also be used to monitor feeding behaviour and movement in order to identify individuals with lower appetites that spend less time feeding and require veterinary attention (Wolfger *et* al., 2015; Barnes *et al*., 2018). While these technologies do offer improved identification, monitoring and traceability; the use in lamb finishing operations is limited by the current high costs associated with the technology along with the rapid throughput of lambs in large operations where the feasibility of the device is outweighed by the short period that lambs are reared. The use of the technology to identify individuals that struggle to adapt to the feedlot diet, shy feeders or unhealthy lambs does present an advantage in early detection and treatment of these lambs (Barnes *et al*., 2018). While the use of RFID tags or accelerometers may not always be practical for every lamb finishing system, it is important that growth of the lambs be monitored and a system incorporated to identify lambs that are either ready for slaughter or slow-growers that have difficulty in adjusting to the feeding conditions. The use of automated drafting scales can then be used to weigh and sort lambs on a regular basis with reduced labour inputs (Morgan-Davies *et al*., 2018). The drafting scales can then be used in conjunction with RFID tags for improved record keeping and precision management (Morris *et al.,* 2012; Brown *et al*., 2015). With improved record keeping and large datasets of production characteristics of large sheep numbers, careful interpretation of the data is needed in order to base informed decisions and adjust management techniques.

To assist with interpretation of data and planning for a production cycle, applications with decision support systems (DSS) can be used. With the advancement of computing and technology, DSS can be used to combine models to actual processes in a software package so as to run simulations that can lead to optimisation. Various applications have been developed to assist in predicting feed intake and production of grazing animals (Donnelly *et al*. 2002), the growth and management of cattle (Tedeschi *et al*., 2004) as well as for the fattening of beef cattle (Shanmugavelu *et al.,* 2012; Walmsley *et al*., 2014). These applications each focus on optimising a specific process of a given production system, with the conditions for each system differing depending on resource inputs and marketing requirements. The role of a DSS should be to simulate the given production system to allow optimisation, as well as to address shortcomings of the operation. Decision support systems for lamb fattening, in particular for South African conditions, are lacking. While the Small Ruminant Nutrition System can be used to predict expected performance of growing lambs in response to a formulated diet (Tedeschi *et al.,* 2010) along with feedlot calculators to predict rearing times; this does not allow for specific accurate predictions of growth, intake or ideal market weight for different South African breeds. The poultry industry has developed models to describe growth and intake of the birds, which can be used to monitor the production of the birds (Emmans, 1989; Gous, 2014). Similar principles used in the models applied to poultry production can be used as a basis for lamb feedlot production models. The following sections will describe the necessary inputs and models required to develop a DSS for feedlot production of different lamb breeds under South African conditions.

## 2.7 Considerations in predicting lamb feedlot performance

As commodity prices increase and market trends shift; pressure is placed on agricultural systems as profit margins become constricted. In order to prevent economic losses, production and management need to intensify. Conventionally sheep farmers would either market their store lambs, soon after weaning, to large feedlot operations or rear the lambs on pasture for slaughter at a later stage. With intensification, many lamb producers are rather opting to finish or fatten their weaner lambs in on-farm feedlots with concentrate diets to a desired slaughter weight, in order to take advantage of marketing an animal with higher value. In order for lambs to be reared with the utmost efficiency, either in a large or on-farm feedlot, precision rearing must be undertaken to ensure profitability and sustainability of the operation. By intensifying the production system and striving to improve feeding efficiency; indirectly producers are also making steps in reducing greenhouse gas emissions and producing meat with a relatively lower carbon footprint (Marino *et al*., 2016).

Precision livestock farming has previously been described as managing livestock production by employing principles and technologies employed by process engineering that will allow the producer improved monitoring of the system which will allow for better decision making (Wathes *et al*., 2008). Precision, or "smart" farming, in turn is a broad field covering a spectrum of applications that vary according to the species of animal farmed with, type of production system, and the practicality of the application. Some of the precision livestock farming applications may include the use of different sensor technologies to assist with identification, behaviour monitoring intake and performance of animals (Halachmi *et al*., 2019). While these devices do allow for large quantities of data to be collected, their suitability to the production system must first be considered. An important part of any precision livestock system should be to be able to predict the performance of the system. The success of an intensive feeding or fattening system can greatly benefit from the development of a DSS which incorporates models describing the growth and intake trends, as well as determining an ideal slaughter weight for optimal profitability.

### 2.7.2 Growth models

Plotting the cumulative growth of an animal against age, from birth to maturity, presents the sigmoidal growth curve (Owens *et al*., 1993). By applying mathematical equations to describe the growth curve, growth models can be developed which can be used to predict the body weight of an individual at a given time point. Popular growth models used to fit the growth curves of livestock species include the Brody, Gompertz, Logistic, Richards and Von Bertallanfy functions (Table 2.5). These growth models can then be used to compare the effects of various treatments on the rate of growth as well as the interaction between different subpopulations or treatments and time, and also to identify heavier individuals at younger ages within a population (Bathaei & Leroy, 1996; Malhado *et al.,* 2009). The advantage of using a model to describe animal growth is that it condenses the data of several different weighings throughout the animal's lifetime into a few parameters that have biological meaning (Bathaei & Leroy, 1996). Most of the growth functions in Table 2.5 are made up of three parameters, while the Richards function includes a fourth parameter in the equation. Knowledge of the parameters and analysis of the growth curves can be exploited to establish efficient feeding strategies as well as an optimal slaughter age (Malhado *et al.,* 2009).

**Table 2.5** Different models used to describe growth with their corresponding equations (Thornley & France, 2007).

| Model | Equation |
|---|---|
| Brody | $W = A(1 - Be^{-kt}) + \varepsilon$ |
| Gompertz | $W = Ae^{Be^{-kt}} + \varepsilon$ |
| Logistic | $W = A(1 + e^{-kt})^{-m} + \varepsilon$ |
| Richards | $W = A(1 - Be^{-kt})^{-m} + \varepsilon$ |
| Von Bertalanffy | $W = A(1 - Be^{-kt})^{3} + \varepsilon$ |

*W* represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight. *B* denotes the proportion of live weight to be gained after birth, while *k* represents the maturation rate. The *m* parameter indicates the point of the curve where inflection occurs. The ε symbol represents the error term that is incorporated in the model.

Different models vary in their suitability for datasets of animals reared under different conditions. The Brody function has been more successful in modelling growth curves made up of datasets from static measurements (Bathaei & Leroy, 1996), while data using continuous weight measurements are more accurately modelled using Gompertz or Von Bertallanfy curves (Keskin *et al*., 2009; Moreira *et al*., 2016). The parameter values of a model vary according the animal or production system that it is reared in. In order to use a growth model in an application to predict growth of animals in a finishing system, it is important that growth measurements of animals reared under ideal conditions are used. In so doing, curves can be developed to represent the genetic potential of the breed for growth. Most growth models contain a parameter representing the asymptotic weight or mature weight of the animal, which is the point at which no further tissue growth occurs and fluctuations in weight are as a result of nutritional or production status (Bathaei & Leroy, 1996). The significance of the asymptotic weight parameter relates to the mature size of the animal which in turn influences the growth rate and maturity of the animal. The *B* parameter represents the proportion of live weight to be gained after birth, while *k* in turn represents the maturation rate. The mature weight has been found to be negatively correlated with the *B* parameter, while the relationship between *B* and *k* parameters has been found to be positively correlated (Bathaei & Leroy, 1996). As a result, animals with higher maturation rates also have lower mature weights. The *m* parameter serves as an indication of the inflection point in the Logistic and Richards functions (da Silva *et al*., 2012).

Differentiation of the growth function gives the change in absolute growth rate of the growing animal, characterised as a bell-shaped curve which increases up to an inflection point and then decreases. The decay in growth rate indicates that the animal is reaching its mature weight. The point of inflection can be described as the point at which maximum growth rate is reached before growth rate decreases. Goshu & Koya (2013), presented a paper on determining the inflection point of different growth curves, with the exception of the Brody function which does not present an inflection point. Emmans (1989) also used a form of the Gompertz function, which incorporates a parameter which indicates the age at when the inflection point of the growth curve is reached. Interpretation of the growth curve and inflection point can be used to determine the periods of maximum growth, and when body fat deposition increases and so reducing feeding efficiency and growth rates as the animal grows to maturity.

### 2.7.2 Modelling feed intake

While growth and production of an animal are dependent on the level of feed intake and quality of nutrition, the level of intake is also influenced by the size of the animal. As an animal grows in mass and different body tissues mature, the maintenance requirements of the growing animal also increases to sustain body tissues, with additional nutrients being required to provide the building blocks for further tissue growth and maturation (Johnson *et al*., 2012). To compensate for this, the size of the gastrointestinal tract increases in relation to the live weight of the animal, making up ~2.3% of live weight with gut content contributing ~6.1% of the body weight of a sheep (Butterfield, 1988). As ~70% of the production costs in an intensive lamb finishing operation are associated with feeding costs (Lima *et al*., 2017), it is important to be able to predict feed intake in the growing lambs.

In relation to body weight, post-weaning feed intake in sheep increases in a curvilinear fashion with an exponential increase followed by a linear decrease after peaking (Butterfield, 1988). Alternatively, this relationship can be modelled using a quadratic function (Ministry of Agriculture, Fisheries and food, 1975; Lewis & Emmans, 2010). Many functions that have been used to estimate intake from live weight (or metabolic weight) have been expanded to include the growth rate (Table 2.6), this emulates the quadratic function by incorporating a time factor with the growth expression.

**Table 2.6** Functions in literature used to describe feed intake (DMI) from body weight (W) and growth rate (ADG).

| Function | Reference |
|---|---|
| $DMI = 0.0711W^{0.75} + 0.0015ADG - 0.124$ | Cannas *et al.,*2004 |
| $DMI = 0.0197W + 0.0682ADG + 0.311$ | National Research Council, 2017 |
| $DMI = 0.0314W^{0.75} + 0.0013ADG + 0.239$ | Vieira *et al.*, 2013 |

The functions in Table 2.6 are useful for predicting intake at a given body weight, provided that the growth rate of the sheep at that weight are known. This may require additional information by differentiating the growth curve to provide the ADG at that stage. A quadratic function has been used to describe this relationship by Lewis & Emmans (2010), accounting for 61% of the variation in intake. While intake models should take the level of production into account; during the growth phase, the quadratic function is suitable to empirically model intake using only a simplistic single input. The study by Lewis & Emmans (2010) also showed that the intake models for breeds with different mature weights differ, with maximum intakes of 1.569-2.623 kg occurring at body weights of 41.7-82.3 kg, as mature weights increased with breed and sex. It is therefore important to determine intake models for different lamb breeds, so as to account for the effects of size and maturity of the different breeds on intake trends. Feed intake in weaned lambs of South African genotypes was previously predicted using net energy requirements of the different breeds (Meissner *et al.,* 1983) (Figure 2.2). These predictions followed a similar curvilinear relationship described above while also illustrating the differences in mature weight on intake trends for the different breeds.

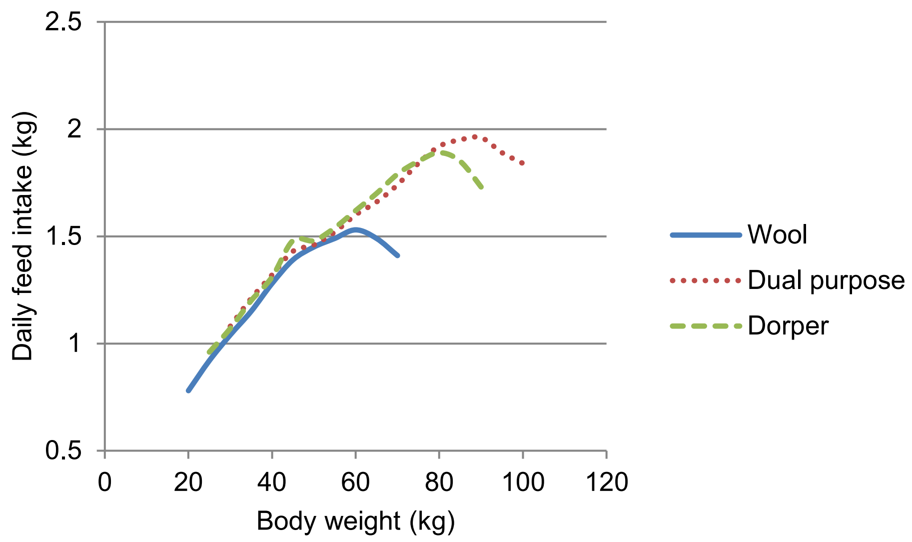


**Figure 2.2** Illustration of the change in feed intake in relation to body weight, as predicted by the net energy requirements for South African wool, dual-purpose and Dorper breeds (adapted from Meissner *et al*., 1983).

In a different study to determine the ideal finishing period of South African lambs, Brand *et al*. (2017) developed equations to determine the growth and feed intake of lambs of different breeds in relation to days in the feedlot (Table 2.7). These proposed functions can be used to make predictions of the production characteristics within a maximum 105 day feeding period, however, as the functions are based on time spent in the feedlot, they do not account for the differences in body weight. In the study, lambs did not attain mature body weights. As a result, there is a close linear relationship between growth and time in the feedlot, therefore equations to predict intake from time in this study also followed a quadratic trend.

**Table 2.7** Equations to predict body weight (*W*) and intake (*DMI*) from days spent in the feedlot (*t*) for Merino (wool), SA Mutton Merino (dual-purpose) and Dorper breeds (Brand *et al*., 2017)

| Breed | Growth function | Intake function |
|---|---|---|
| Merino | $W = 32.0 + 0.219t$ | $DMI = 0.363 - 0.001t - 0.00001t^2$ |
| SA Mutton Merino | $W = 31.7 + 0.307t$ | $DMI = 0.520 - 0.004t + 0.00003t^2$ |
| Dorper | $W = 32.1 + 0.306t$ | $DMI = 0.031 + 0.006t - 0.00004t^2$ |

While body weight is one of the main factors influencing the level of feed intake and is the starting point in predicting feed intake in ruminants (Lewis & Emmans, 2010). A clear understanding of feed intake is important for manipulation of diets in order to meet the requirements of an animal in order to realise optimal production levels (Illius *et al*., 2000). The prediction and control of feed intake are complex principles, with factors which influence feed intake ranging from substrate or nutritional quality factors, physical aspects of the feed affecting gut fill, passage rate and digestion kinetics as well as animal and environmental factors (Ingvartsen, 1994; Allen, 1996; Faverdin 1999). The short term control of feed intake in ruminants is triggered by the presence of feed in the rumen, either through neural messages to the central nervous system originating from the rumen walls (Della Fera & Baile, 1984), or metabolic pathways by chemical feedback from fermentation end products such as volatile fatty acids and ammonia (Faverdin, 1999). In the long term, it is hypothesised that ruminants consume feed in order to satisfy nutritional requirements as well as maintain rumen function (Faverdin, 1999). This may involve the release of hormonal factors or neuropeptides such as leptin from body tissues, in order to trigger an appetite stimulating or suppressing response, depending on the nutritional status (Pulina *et al*., 2013). Predicting intake from the above mechanisms relies on mechanistic modelling approaches which provide detailed explanations of the underlying systems influencing feed intake. Empirical modelling of the body of the system on the other hand is less descriptive but does provide better predictive accuracy (Pulina *et al*., 2013). While it is understood that animal factors such as size, genotype, physiological and production status contribute greatly to the level of feed intake (Vieira *et al*., 2013), specific descriptions of these factors and how they influence intake are not updated for modern production systems. This again illustrates the importance of developing models to predict intake of growing lambs of different breeds.

### 2.7.3 Predicting subcutaneous fat cover

The South African carcass classification system for lamb is based on the degree of fat cover which in turn is an indicator of carcass composition and quality (Bruwer *et al*., 1987b). Conventionally, slaughter results and comparative slaughter studies have been used to describe the degree of fatness of sheep at different stages and so determine an ideal slaughter weight with an optimal degree of fatness (Strydom *et al*., 2009; Brand *et al.,* 2018). Brand *et al.* (2018) determined that the optimal slaughter weight for both wool and dual-purpose lambs was 42.7 kg, while earlier maturing Dorper lambs should be slaughtered at 36.0 kg live weight. These studies are costly and relevant results can only be obtained from the carcass after the animal has been slaughtered. Therefore, methods to predict final carcass merit from live animals is needed so as to determine when the animal has reached an ideal fatness according to market specifications (Hamlin *et al*., 1995).

Previous methods of estimating body composition involved the use of live weight, visual appraisal and condition scoring while ultrasound, X-ray computed tomography and nuclear magnet resonance can be used to predict tissue composition of the live animal (Stanford *et al*., 1998). Of the technologies which can be applied, the use of portable ultrasound scanners seems the most practical in terms of cost and access to the technology (Stanford *et al*., 1998). The use of ultrasound technology has previously been used to determine the composition of the lamb carcass from measurements on the live animal (Hopkins *et al.,* 1993; Hopkins *et al.,* 1996; Silva *et al.,* 2005). Ultrasound scans allow for measurements to be made on scan images to determine the quantities of fat and muscle tissue. In determining carcass composition, Bruwer *et al.* (1987b) found that the best correlations were found by measuring the carcass fat depth on the *longissimus lumborum* muscle between the third and fourth lumbar vertebrae of the lamb carcass. For ease of measurement, other studies use the position of the 13$^{th}$ rib as the measurement site on the *longissimus* muscle as the two sites lie in close proximity to each other and are highly correlated (Grill *et al.,* 2015*)*. Ultrasound fat depth measurements have been shown to have higher correlations with carcass fat depth, lean meat yield and fat yield than correlations with muscle tissue depth (Hopkins *et al*., 2007; Grill *et al*., 2015).

It has been shown that subcutaneous fat, among other fat depots, increases with the rearing period and carcass weight of lambs (Brand *et al*., 2018). Stanford *et al.* (2001) used ultrasound scans to demonstrate the subcutaneous fat deposition rates of ram (16.3 μm/day) and ewe (19.2 μm/day) Romanov-Suffolk cross lambs between the ages of 60-135 days. Hopkins *et al.* (1993) showed that Terminal cross Merino lambs on average accrete subcutaneous fat at a rate of 7 μm/day during a 93 day growth period from 27.7 to 43.7 kg body weight. Under feedlot conditions, it is necessary to be able to predict the fat cover of a lamb at a given body weight, to determine when the lamb is market ready and prevent over-fattening. With the spectrum of South African sheep breeds varying in maturation rate and fat deposition characteristics, live weight alone cannot be used as reliable indicator. Fat deposition rate in growing lambs of South African sheep breeds are yet to be described, with the use of ultrasound technology providing the opportunity to map this growth until lambs attain mature body weights.

### 2.7.4 Lamb meat quality

After slaughter, lamb carcasses are chilled before being sold to meat processors that divide the carcass into cuts according to retail market demands. The carcass classification system was developed in order to present information of the carcass and its expected quality characteristics to all role players throughout the meat value chain (Webb, 2015). According to these descriptions, processors can make informed decisions regarding the carcass being purchased and how butchery must take place for optimal profitability. The purchasing of fatter carcasses may also require trimming of carcass fat to provide a more desirable product, which also influences profitability (Strydom *et al*., 2009).

The demand for different cuts of lamb varies between different regions and economic classes. Though, the portions that are typically considered to be high value, due to the higher meat yield include the hindquarters, loin and prime rib (Burger *et al*., 2013). Meat type sheep breeds that have been bred for improved conformation and meat production produce carcasses with heavier yields of these cuts than wool or indigenous breeds (Tshabalala *et al.,* 2003; Cloete *et al*., 2012). The traditional butchers block test is used to determine the economic value of the carcass after it has been cut into primal or secondary retail cuts. The overall profitability can be manipulated by the way that the cuts are made - by butchering the carcass in such a way to increase the yield of the higher value cuts.

The meat consumer expects uniform quality each time they purchase a meat product. Using information based on age and fatness of the carcass, the carcass classification system provides an indication of the intrinsic quality factors of the meat (Bruwer *et al*., 1987a; Webb, 2015), while conformation may give an indication of the size of the high value primal cuts. Lamb is regarded as a tender meat, while mutton is associated with tougher meat, due to the presence of more stable bindings of the connective tissue that develop as the animal ages (Schönfeldt *et al*., 1993). Fat is also an indicator of juiciness and flavour, but may also be associated with health awareness, particularly high levels of saturated fatty acids in meat from ruminants which have been linked to cardiovascular diseases (Webb & O' Neill, 2008). While the carcass classification system does provide the information to improve uniformity of the size of certain cuts, as well as the expected quality cues, breed differences may arise influencing the perception of consumers. It is therefore important to determine whether the effect of breed is accounted for within the carcass classification system for meat yield and quality characteristics.

### 2.7.5 Wool growth

While wool production is not the primary goal of a lamb finishing system, it may provide a supplementary income to buffer profit margins. Shearing the wool of sheep has been shown to induce a degree of cold stress causing the animals to ingest more feed (Dabiri *et al.,* 1996) which may improve growth rates. This may be applied to feedlot lambs in order to improve production characteristics and reduce rearing time. Keady & Hanrahan (2015) were able to show that intake could be increased by shearing lambs before entering the feedlot. However, the same study did not show any improvements in growth rate, with an increase in FCR and so reducing the feed efficiency, which is undesirable

Should feedlot operators decide to exploit the additional income from wool, they would require information on the wool growth rate of wool breeds. This then gives an indication of the weight of the fleece that can be obtained from the lamb, and the operator can decide whether it is feasible to shear lambs either upon entry to the feedlot or prior to slaughter, should wool prices be favourable. Du Plessis & De Wet (1981) reported wool growth rates of

27.1, 14.6 and 16.9 g/day for Merino, Dohne Merino and South African Mutton Merino lambs, respectively. Wool growth of Dormer lambs, though, has as of yet not been published. By combining models to predict the wool growth and fleece weight with the previously mentioned production characteristics, a better decision can be made on how to adapt the management practices in order to obtain the maximum profitability from the lambs. It also provides nutritionists with information on how nutrients can be partitioned towards body tissue or wool growth.

## 2.8 Conclusion

While lamb meat prices increase, the profit margins in a lamb finishing system remain narrow and so require intensive management to maintain profitability. An understanding of the growth and fat deposition characteristics of the different breeds are required along with an understanding of feed intake dynamics in order to rear a lamb profitably to produce a carcass meeting market specifications. With the advancement of technology, precision lamb finishing can be incorporated in order to assist with planning and determining an optimal slaughter weight. To do this, there is a need to develop a precision lamb finishing model that takes the changes in growth, feed intake and fat deposition into account for different purebred South African sheep breeds, as well as popular terminal crossbreeds. By combining these models with economic values, simulations can be run in order to determine the optimal slaughter weight of the lambs for maximal profitability. Additional product factors such as wool growth and meat yield and quality can be incorporated in order to widen the scope of the producers in determining the most applicable management or marketing technique for optimum profitability.

While precision livestock rearing is being incorporated into many production systems, the South African lamb feedlotting industry still relies on basic feedlot profitability calculators with production parameter estimates. The development of more accurate models for predicting the production characteristics of different South African sheep breeds will greatly benefit the industry in applying more strategic management to improve profitability.

## References

Addah, W., Ayantunde, A., Okine, E.K., 2017. Effects of restricted feeding and re-alimentation of dietary protein or energy on compensatory growth of sheep. S. Afr. J. Anim. Sci., 47, 389-396.

Alfonso, M., Sañudo, C., Berge, P., Fisher, A.V., Stamataris, C., Thorkelsson, G., Piasentier, E., 2001. Influential factors in lamb meat quality. Acceptability of specific designations, in: Rubino, R., Morand-Fehr, P., (eds) Production systems and product quality in sheep and goats, pp. 19-28.

Allen, M.S., 1996. Physical constraints on voluntary intake of forages by ruminants. J. Anim. Sci., 74, 3063-3075.

Andargachew, K., Brokken, R.F., 1993. Intra-annual sheep price patterns and factors underlying price variations in the central highlands of Ethiopia. Agric. Econ., 8: 125-138.

Barnes, A.L., Wickham, S.L., Admiraal, R., Miller, D.W., Collins, T., Stockman, C., Fleming, P.A., 2018. Characterization of inappetent sheep in a feedlot using radio-tracking technology. J. Anim. Sci., 96, 902-911.

Bathaei, S.S., Leroy, P.L., 1996. Growth and mature weight of Mehraban Iranian fat-tailed sheep. Small Rumin. Res., 22, 155-162.

Ben Salem, H., Nefzaoui, A., 2003. Feed blocks as alternative supplements for sheep and goats. Small Rumin. Res., 49, 275-288.

Bello, J.M., Mantecón, A.R., Rodriguez, M., Cuestas, R., Beltran, J.A., Gonzalez, J.M., 2016. Fattening lamb nutrition. Approaches and strategies in feedlot. Small Rumin. Res., 142, 78-82.

Brand, T.S., 2000. Grazing behaviour and diet selection by Dorper sheep. Small Rumin. Res., 36, 147-158.

Brand, T.S., Genis, M.P., Hoffman, L.C., Van De Vyver, W.F.J., Swart, R., Jordaan, G.F., 2013. The effect of dietary energy and the inclusion of a β-adrenergic agonist in the diet on the meat quality of feedlot lambs. S. Afr. J. Anim. Sci. 43, 140-145.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci., 47, 26-33.

Brand, T.S., Van Der Westhuizen, E.J., van Der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci., 48, 477-488.

Brown, D.J., Savage, D.B., Hinch, G.N., Hatcher, S., 2015. Monitoring liveweight in sheep is a valuable management strategy: a review of available technologies. Anim. Prod. Sci., 55, 427-436.

Bruwer, G.G., Grobler, I., Smit, M., Naudé, R.T., Vosloo, W.A., 1987a. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 4. The influence of age, carcase mass and fatness on meat quality characteristics. S. Afr. J. Anim. Sci., 17, 95-103.

Bruwer, G.G., Naude, R.T., Du Toit, M.M., Cloete, A., Vosloo, W.A., 1987b. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 2. The use of fat measurements as predictors of carcase composition. S. Afr. J. Anim. Sci., 17, 85-89.

Bruwer, G.G., Naudé, R.T., Vosloo, W.A., 1987c. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 3. Fatness score, conformation score and carcase mass as predictors of carcase composition. S. Afr. J. Anim. Sci., 17, 90-94.

Burger, A., Hoffman, L.C., Cloete, J.J.E., Muller, M., Cloete, S.W.P., 2013. Carcass composition of Namaqua Afrikaner, Dorper and SA Mutton Merino ram lambs reared under extensive conditions. S. Afr. J. Anim. Sci., 43, 27-32.

Butterfield, R.M., 1988. New concept of sheep growth. Department of Veterinary Anatomy, University of Sydney. Australia. pp 2-33.

Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N., Van Soest, P.J., 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci., 82, 149-169.

Cloete, J.J E., Hoffman, L.C., Cloete, S.W.P., Fourie, J.E., 2004b. A comparison between the body composition, carcass characteristics and retail cuts of South African Mutton Merino and Dormer sheep. S. Afr. J. Anim. Sci., 34, 44-51.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. Meat Sci., 91, 318-324.

Cloete, S.W.P., Cloete, J.J.E., Durand, A., Hoffman, L.C., 2003. Production of five Merino type lines in a terminal crossbreeding system with Dormer or Suffolk sires. S. Afr. J. Anim. Sci., 33, 223-232.

Cloete, S.W.P., De Villiers, T.T., 1987. Production parameters for a commercial Dorper flock on extensive pastures. S. Afr. J. Anim. Sci., 17, 121-127.

Cloete, S.W.P., Olivier, J.J., Olivier, W.J., 2007. Genetic change in South African Merino resource flocks. Proc. Assoc. Advmt. Anim. Breed. Genet., 17, 320-323.

Cloete, S.W.P., Olivier, J.J., Sandenbergh, L., Snyman, M.A., 2014. The adaption of the South Africa sheep industry to new trends in animal breeding and genetics: A review. S. Afr. J. Anim. Sci., 44, 307-321.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V., 2001. Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric., 41, 145-153.

Cloete, S.W.P., Snyman, M.A., Herselman, M.J., 2000. Productive performance of Dorper sheep. Small Rumin. Res., 36, 119-135.

Cloete, S.W.P., Van Wyk, J.B., Neser, F.W.C., 2004a. Estimates of genetic and environmental (co) variances for live weight and fleece traits in yearling South African Mutton Merino sheep. S. Afr. J. Anim. Sci., 34, 37-43.

Coetzee, J., 2004. Latest sheep farming practices for maximum profit generation (translated from Afrikaans). Copyright Jasper Coetzee Consulting, pp 230-240.

Dabiri, N., Morris, S.T., Wallentine, M., McCutcheon, S.N., Parker, W.J., Wickham, G.A., 1996. Effects of pre-lamb shearing on feed intake and associated productivity of May-and August-lambing ewes. New Zeal. J. Agric. Res., 39, 53-62.

da Silva, L.S.A., Fraga, A.B., da Silva, F.D.L., Beelen, P.M.G., de Oliveira Silva, R.M., Tonhati, H., da Costa Barros, C., 2012. Growth curve in Santa Inês sheep. Small Rumin. Res., 105, 182-185.

Davel, M., Bosman, M.J.C., Webb, E.C., 2003. Effect of electrical stimulation of carcasses from Dorper sheep with two permanent incisors on the consumer acceptance of mutton. S. Afr. J. Anim. Sci., 33, 206-212.

De Bruyn, J.F., 1991. Production and product characteristics of different cattle genotypes under feedlot conditions. D.Sc. (Agric) Thesis. University of Pretoria.

Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S., Courbois, C., 1999. Livestock to 2020 the next food revolution. Food Agriculture and the Environment Discussion Paper 28, International food policy institute, pp. 1-52.

Della-Fera, M.A., Baile, C.A., 1984. Control of feed intake in sheep. J. Anim. Sci., 59, 1362-1368.

Department of Agriculture, Forestry & Fisheries. 2019. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63.

(https://www.daff.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202019.pdf?timestamp=1568549611726 ).

Donnelly, J.R., Freer, M., Salmon, L., Moore, A.D., Simpson, R.J., Dove, H., Bolger, T.P., 2002. Evolution of the GRAZPLAN decision support tools and adoption by the grazing industry in temperate Australia. Agric. Syst., 74, 115-139.

Du Plessis, J.J., De Wet, P.J., 1981. Nitrogen utilization by sheep. 1. Nitrogen utilization by weaned lambs of a wool, a wool/mutton and a mutton/wool breed for wool and body protein formation. Agroanimalia, 13: 21-27.

Emmans G.C., 1989. Chapter 8 The growth of turkeys. In: Nixey, C., Grey, T.C. (eds), Recent advances in turkey science (Poultry science symposium number 21). By Butterworth and Heineman. Ltd.

Ermias, E., Yami, A., Rege, J.E.O., 2002. Fat deposition in tropical sheep as adaptive attribute to periodic feed fluctuation. J. Anim. Breed. Genet., 119, 235-246.

FAOSTAT.2019. http://www.fao.org/faostat/en/#data/RL (Accessed 18 October 2019).

Faverdin, P., 1999. The effect of nutrients on feed intake in ruminants. Proc. Nutr. Soc., 58, 523-531.

Field, R.A., Snowder, G.D., Maiorano, G., McCormick, R.J., Riley, M.L., 1993. Growth and slaughter characteristics of ram and wether lambs implanted with zeranol. J. Anim. Sci., 71, 631-635.

Finlayson, J.D., Cacho, O.J., Bywater, A.C., 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agric. Syst., 48, 1-25.

Gerrits, W.J., Tolman, G.H., Schrama, J.W., Tamminga, S., Bosch, M.W., Verstegen, M.W., 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci., 74, 2129-2139.

Goshu, A.T., Koya, P.R., 2013. Derivation of inflection points of nonlinear regression curves-implications to statistics. AM. J. Theor. Appl. Stat., 2, 268-272.

Gous, R.M., 2014. Modeling as a research tool in poultry science. Poult. Sci., 93, 1-7.

Government Notice No. R. 863 of 1 September 2006. Agricultural product standards Act 119 of 1990. Regulations regarding the classification and marketing of meat in the Republic of South Africa.

Greenhalgh, J.F.D., Reid, G.W., 1973. The effects of pelleting various diets on intake and digestibility in sheep and cattle. Anim. Sci., 16, 223-233.

Grill, L., Ringdorfer, F., Baumung, R., Fuerst-Waltl, B., 2015. Evaluation of ultrasound scanning to predict carcass composition of Austrian meat sheep. Small Rumin. Res., 123, 260–268.

Halachmi, I., Guarino, M., Bewley, J., Pastell, M., 2019. Smart animal agriculture: application of real-time sensors to improve animal well-being and production. Annu. Rev. Anim. Biosci., 7, 403-425.

Hamlin, K.E., Green, R.D., Cundiff, L.V., Wheeler, T.L., Dikeman, M.E., 1995. Real-time ultrasonic measurement of fat thickness and longissimus muscle area: II. Relationship between real-time ultrasound measures and carcass retail yield. J. Anim. Sci., 73, 1725-1734.

Hopkins, D. L., Hall, D. G., Luff, A. F., 1996. Lamb carcass. 3. Describing changes in carcasses of growing lambs using real-time ultrasound and the use of these measurements for estimating the yield of saleable meat. Aust. J. Exp. Agric., 36, 37–43.

Hopkins, D.L., Pirlot, K.L., Roberts, A.H.K. & Beattie, A.S., 1993. Changes in fat depths and muscle dimensions in growing lambs as measured by real-time ultrasound. Aust. J. Exp. Agric., 33, 707-712.

Hopkins, D.L., Stanley, D.F. & Ponnampalam, E.N., 2007. Relationship between real-time ultrasound and carcass measures and composition in heavy sheep. Aust. J. Exp. Agric., 47, 1304–1308.

Illius, A.W., Jessop, N.S., Gill, M., 2000. Mathematical models of food intake and metabolism in ruminants, in: Cronjé P.B., (ed) Ruminant physiology, digestion, metabolism growth and reproduction (). CABI Publishing, Wallingford, UK, pp.21-40.

Ingvartsen, K.L., 1994. Models of voluntary food intake in cattle. Livest. Prod. Sci., 39, 19-38.

Johnson, I.R., France, J., Thornley, J.H.M., Bell, M.J., Eckard, R.J., 2012. A generic model of growth, energy metabolism, and body composition for cattle and sheep. J. Anim. Sci., 90, 4741-4751.

Kempster, A.J., 1981. Fat partition and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Sci., 5, 83-98.

Keskin, I., Dag, B., Sariyel, V., Gokmen, M., 2009. Estimation of growth curve parameters in Konya Merino sheep. S. Afr. J. Anim. Sci., 39, 163-168.

Keady, T.W.J., Hanrahan, J.P., 2015. Effects of shearing, forage type and feed value, concentrate feed level, and protein concentration on the performance of housed finishing lambs. J. Anim. Sci., 93, 306-318.

Kleen, J.L., Hooijer, G.A., Rehage, J., Noordhuizen, J.P.T.M., 2003. Subacute ruminal acidosis (SARA): a review. J. Vet. Med. A., 50, 406-414.

Lawrence, T. L. J., Fowler, V. R., Novakofksi J. E. 2012. Growth of farm animals. Second edition. CABI. pp. 216-228

Lewis, R.M., Emmans, G.C., 2010. Feed intake of sheep as affected by body weight, breed, sex, and feed composition. J. Anim. Sci., 88, 467-480.

Lewis, R.M., Notter, D.R., Hogue, D.E., Magee, B.H., 1996. Ewe fertility in the STAR accelerated lambing system. J. Anim. Sci., 74, 1511-1522.

Lima, N.L.L., Ribeiro, C.R.D.F., Sá, H.C.M.D., Leopoldino-Júnior, I., Cavalcanti, L.F.L., Santana, R.A.V., Furusho-Garcia, I.F., Pereira, I.G., 2017. Economic analysis, performance, and feed efficiency in feedlot lambs. R. Bras. Zootec., 46, 821-829.

Malhado, C., Carneiro P., Affonso P., Souza Jr A., Sarmento J., 2009. Growth curves in Dorper sheep crossed with the local brazilian breeds, Morada nova, Rabo largo, & Santa inês. Small Rumin. Res.. 84, 16-21.

Marino, R., Atzori, A.S., D'Andrea, M., Iovane, G., Trabalza-Marinucci, M., Rinaldi, L., 2016. Climate change: Production performance, health issues, greenhouse gas emissions and mitigation strategies in sheep and goat farming. Small Rumin. Res., 135, 50-59.

Meissner, H.H., Hofmeyr, H.S., Van Rensburg, W.J.J., Pienaar, J.P., 1983. Classification of livestock for realistic prediction of substitution values in terms of a biologically defined Large Stock Unit. Technical Communication 175. Department of Agriculture, Republic of South Africa.

Meissner, H.H., Scholtz, M.M., Engelbrecht, F.A., 2013. Sustainability of the South African Livestock Sector towards 2050 Part 2: Challenges, changes and required implementations. S. Afr. J. Anim. Sci., 43, 289-319.

Milne, C., 2000. The history of the Dorper sheep. Small Rumin. Res., 36, 99-102.

Ministry of Agriculture, Fisheries and Food (MAFF), 1975. Energy allowances and feeding systems for ruminants. Tech Bull. 33, Ministry of Agriculture and Fisheries. Her Majesty's Stationary Office, London, pp 79.

Mohapatra, A., Shinde, A., 2018. Fat-tailed sheep-an important sheep genetic resource for meat production in tropical countries: an overview. Ind. J. Small Rumin., 24, 1-17.

Moreira, R.P., Pedrosa, V.B., Falcão, P.R., de Fátima Sieklicki, M., Rocha, C.G., dos Santos, I.C., Ferreira, E.M., de Souza Martins, A., 2016. Growth curves for Ile de France female sheep raised in feedlot. *Semin-Ciênc. Agrár*, 37, 303-310.

Morgan-Davies, C., Lambe, N., Wishart, H., Waterhouse, T., Kenyon, F., McBean, D., McCracken, D., 2018. Impacts of using a precision livestock system targeted approach in mountain sheep flocks. Livest. Sci., 208, 67-76.

Morris, J.E., Cronin, G.M., Bush, R.D., 2012. Improving sheep production and welfare in extensive systems through precision sheep management. Anim. Prod. Sci., 52, 665-670.

Najari, S., Gaddoun, A., Hamouda, M.B., Djemali, M., Khaldi, G., 2007. Growth model adjustment of local goat population under pastoral conditions in Tunisian arid zone. J. Agron, 6, 61-67

National Research Council, 2017. Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids. National Academic Press, Washington DC., U.S.A.

Negussie, E., Rottmann, O.J., Pirchner, F., Rege, J.E.O., 2003. Patterns of growth and partitioning of fat depots in tropical fat-tailed Menz and Horro sheep breeds. Meat Sci., 64, 491-498.

Neser, F.W.C., Erasmus, G.J., Van Wyk, J.B., 2000. Genetic studies on the South African Mutton Merino: growth traits. S. Afr. J. Anim. Sci., 30, 172-177.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci., 71, 3138-3150.

Pannier, L., Gardner, G.E., Pethick, D.W., 2019. Effect of Merino sheep age on consumer sensory scores, carcass and instrumental meat quality measurements. Anim. Prod. Sci., 59, 1349-1359.

Peters, F.W., Kotze, A., Van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res., 90, 101-108.

Pienaar, G.H., Einkamerer, O.B., Van der Merwe, H.J., Hugo, A., Scholtz, G.D.J., Fair, D.M., 2012. The effects of an active live yeast product on the growth performance of finishing lambs. S. Afr. J. Anim. Sci., 42, 464-468.

Price, M.M., Einkamerer, O.B., De Witt, F.H., Greyling, J.P.C., Fair, M.D., 2009. The effect of dietary ionophores on feedlot performance of lambs. S. Afr. J. Anim. Sci., 39, 141-144.

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. R. Bras. Zootec., 42, 675-690.

Qwabe, S.O., van Marle-Köster, E., Visser, C., 2013. Genetic diversity and population structure of the endangered Namaqua Afrikaner sheep. Trop. Anim. Health Prod., 45, 511-516.

Red Meat Producers Organisation., 2019. (http://www.rpo.co.za/information-centre/absa/weekly-prices/) Accessed 1 September 2019.

Rust, J.M., Rust, T., 2013. Climate change and livestock production: A review with emphasis on Africa. S. Afr. J. Anim. Sci., 43, 255-267.

Sandenbergh, L., Cloete, S.W.P. Olivier, J.J., 2018, Assessing the occurrence of hybridisation in endangered indigenous sheep. In Proc. of the 11th World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand (pp. 11-16).

Schoeman, S.J., Cloete, S.W.P., Olivier, J.J., 2010. Returns on investment in sheep and goat breeding in South Africa. Livest. Sci., 130, 70-82.

Schönfeldt, H.C., Naude, R.T., Bok, W., Van Heerden, S.M., Smit, R., Boshoff, E., 1993. Flavour-and tenderness-related quality characteristics of goat and sheep meat. Meat Sci., 34, 363-379.

Schönfeldt, H.C., Van Heerden, S.M., Sainsbury, J., Gibson, N., 2011. Nutrient content of uncooked and cooked meat from South African classes A2 lamb and C2 mutton. S. Afr. J. Anim. Sci., 41, 141-145.

Scott, J.T., Broadbent, E.E., 1972. A computerized cattle feeding program for replacement and ration formulation. Illinois Agric. Econ., 12, 16-25.

Shanmugavelu, S., Wong, H.K., Mardhati, M., 2012. A beef fattening decision support system. Mal. J. Vet. Res., 3, 7-13.

Silva, S.R., Gomes, M.J., Dias-da-Silva, A., Gil, L.F., Azevedo, J.M.T.D., 2005. Estimation in vivo of the body and carcass chemical composition of growing lambs by real-time ultrasonography. J. Anim. Sci., 83, 350–357.

Soma, P., Kotze, A., Grobler, J.P., Van Wyk, J.B., 2012. South African sheep breeds: Population genetic structure and conservation implications. Small Rumin. Res*.,* 103, 112-119.

Snyman, M.A., Herselman, M.J., 2005. Comparison of productive and reproductive efficiency of Afrino, Dorper and Merino sheep in the False Upper Karoo. S. Afr. J. Anim. Sci., 35, 98-108.

Stanford, K., Bailey, D.R.C., Jones, S.D.M., Price, M.A., Kemp, R.A., 2001. Ultrasound measurement of longissimus dimensions and backfat in growing lambs: effects of age, weight and sex. Small Rumin. Res*.,* 42, 189–195.

Stanford, K., Jones, S.D.M., Price, M.A., 1998. Methods of predicting lamb carcass composition: A review. Small Rumin. Res*.,* 29, 241-254.

Strydom, P.E., Van Heerden, S.M., Van Heerden, H.C., Kruger, R., Smith, M.F., 2009. The influence of fat score and fat trimming on primal cut composition of South African lamb. S. Afr. J. Anim. Sci., 39, 233-242.

Tainton N.M., 1988. A consideration of veld condition assessment techniques for commercial livestock production in South Africa, J. Grassl. Soc. S. Afric., 5, 76-79.

Tedeschi, L.O., Cannas, A., Fox, D.G., 2010. A nutrition mathematical model to account for dietary supply and requirements of energy and other nutrients for domesticated small ruminants: The development and evaluation of the Small Ruminant Nutrition System. Small Rumin. Res*.,* 89, 174-184.

Tedeschi, L.O., Fox, D.G., Guiroy, P.J., 2004. A decision support system to improve individual cattle management. 1. A mechanistic, dynamic model for animal growth. Agric. Syst*.*, 79, 171-204.

Terblanche, S., Brand, T.S., Jordaan, J.W., Van der Walt, J.C., 2012. Production response of lambs receiving creep feed while grazing two different pastures. S. Afr. J. Anim. Sci., 42, 535-539.

Thornley, J.H.M., France, J., 2007. Mathematical models in agriculture: Quantitative methods for the plant, animal and ecological sciences. Second edition. CABI. United Kingdom.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., De Kock, H.L., 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Sci., 65, 563-570.

Van de Vyver, W.F.J., Beukes, J.A., Meeske, R., 2013. Maize silage as a finisher feed for Merino lambs. S. Afr. J. Anim. Sci., 43, 116-120.

Van Wyk, J.B., Fair, M.D., Cloete, S.W.P., 2003. Revised models and genetic parameter estimates for production and reproduction traits in the Elsenburg Dormer sheep stud. S. Afr. J. Anim. Sci., 33, 213-222.

Van Wyk, J.B., Swanepoel, J.W., Cloete, S.W., Olivier, J.J., Delport, G.J., 2008. Across flock genetic parameter estimation for yearling body weight and fleece. S. Afr. J. Anim. Sci., 38, 31-37.

Vieira, P.A.S., Pereira, L.G.R., Azevêdo, J.A.G., Neves, A.L.A., Chizzotti, M.L., dos Santos, R.D., de Araújo, G.G.L., Mistura, C., Chaves, A.V., 2013. Development of mathematical models to predict dry matter intake in feedlot Santa Ines rams. Small Rumin. Res., 112, 78-84.

Vorster , M., Botha, P., Hobson, F.O. 1983. The utilization of karoo veld by livestock, Proc. Annual Congresses of the Grassland Society of Southern Africa, 18, 35-39.

Walmsley, B.J., McPhee, M.J., Oddy, V.H., 2014. Development of the BeefSpecs fat calculator to assist decision making to increase compliance rates with beef carcass specifications. Anim. Prod. Sci., 54, 2003-2010.

Wathes, C.M., Kristensen, H.H., Aerts, J.M., Berckmans, D., 2008. Is precision livestock farming an engineer's daydream or nightmare, an animal's friend or foe, and a farmer's panacea or pitfall?. Comput. Electron. Agr., 64, 2-10.

Watson, R.H., Alexander, G., Cumming, I.A., MacDonald, J.W., McLaughlin, J.W., Rizzoli, D.J., Williams, D., 1968. Reduction of perinatal loss of lambs in winter in western Victoria by lambing in sheltered individual pens. Proc. Aust. Soc. Anim. Prod.; 7th Biennial meeting. pp 243-249

Webb, E.C., Casey, N.H., 2010. Physiological limits to growth and the related effects on meat quality. Livest. Sci., 130, 33-40.

Webb, E.C., 2015. Description of carcass classification goals and the current situation in South Africa. S. Afr. J. Anim. Sci., 45, 229-233.

Webb, E.C., Allen, J., Morris, S.D., 2018. Effects of non-steroidal growth implant and dietary zilpaterol hydrochloride on growth and carcass characteristics of feedlot lambs. S. Afr. J. Anim. Sci., 48, 601-608.

Webb, E.C., O'neill, H.A., 2008. The animal fat paradox and meat quality. Meat Sci., 80, 28-36.

Webster, A.J.F., 1980. The Energetic efficiency of growth. Livest. Prod. Sci., 7, 243-252.

Wolfger, B., Timsit, E., Pajor, E.A., Cook, N., Barkema, H.W., Orsel, K., 2015. Accuracy of an ear tag-attached accelerometer to monitor rumination and feeding behavior in feedlot cattle. J. Anim. Sci., 93, 3164-3168.

Wood, J.D., MacFie, H.J.H., 1980. The significance of breed in the prediction of lamb carcass composition from fat thickness measurements. Anim. Sci., 31, 315-319.

# Chapter 3 - Application of growth models to different sheep breed types in South Africa


## Abstract

In order to determine the growth trends of seven sheep breeds that are popular in South African commercial production systems (Dohne Merino, Dormer, Dorper, Meatmaster, Merino, SA Mutton Merino and White Dorper), body weight data was collected from lambs of each breed from birth until they were assumed to have attained maturity at one year of age. These breeds were selected to represent wool, meat and dual-purpose types, as well as a range of maturity types, ranging from early to late maturing. From the data, individual growth curves were extrapolated and the Brody, Gompertz, Logistic and Von Bertalanffy models fitted to the curves. The model parameters were compared between breeds for each model fitted and the respective models evaluated for describing the growth in various breeds. The Brody model was found to be unsuitable, as the model over-predicted the mature weights of the sheep and presented the highest RMSE and AIC values, as well as the lowest $R^2$ values for each breed. The Gompertz, Logistic and Von Bertalanffy models were found to be more suitable in accurately predicting the growth of the different production groups. The Logistic model presented the lowest RMSE and AIC values, and highest $R^2$ values, in each case where the model was fitted to the production group and is the most accurate in predicting the growth of the slaughter lambs of the breeds in this study.


**Keywords:** *Growth curve; Predictions; Maturity; Wool type; Meat type*

## 3.1 Introduction

Growth is defined as the increase in the number of somatic cells (hyperplasia) and size of the cells (hypertrophy) making up the tissues of an organism (Owens *et al*., 1993). The complex system of growth of an animal must be carefully evaluated for profitable and efficient rearing practices (Nadarajah *et al*., 1984). Plotting the cumulative weights of an animal against its age, from birth through to maturity, presents a sigmoidal pattern that is characteristic of a growth curve. Initially the curve follows a lag phase, then after birth exhibits a prepubescent self-accelerating phase of rapid growth; as this growth passes a point of inflection it undergoes post-pubescent self-inhibition, slowing growth rates as the individual nears its mature live weight (Owens *et al*., 1993). This mature live weight can be defined as the average weight that an individual can attain after growth rate has plateaued according to its genetic potential, if conditions for growth have not been limited. Variations in the mature weight are expected to

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occur during an animal's lifetime as it undergoes various physiological stages and is exposed to varying nutritional levels.

Modelling the growth of sheep can be done either by using mechanistic approaches of internal mechanisms that offer explanations of growth but lack predictive power, whereas, empirical models have low explicative value but excel in predictive performance (Pulina *et al*., 2013). There are also different manners in which a weight-age database for modelling can be compiled. Genetic studies of the growth models of sheep generally rely on static or cross-sectional measurements recorded either at specific growth stages or at different ages to give the mean growth curve of a population, but lacks representation of individual development. To get a true reflection of the growth of slaughter animals, longitudinal recording of a complete set of measurements of each individual is necessary throughout the growth process (Fitzhugh, 1976). Mathematical models can then be applied in order to describe the growth of the animal as well as aid in predicting marketing weights.

The South African sheep flock consists of about 19.9 million head of sheep, producing more than 177 000 tonnes of mutton from the commercial sector (DAFF, 2018). The national flock is made up of a number of breeds that are bred for either wool or meat production or dual-purpose breeds that are reared to produce both commodities. The Merino is the main wool producing sheep in South Africa, with the Dohne Merino and SA Mutton Merino (SAMM) being regarded as dual-purpose breeds. The major sheep breeds reared for meat production are the Dormer and Dorper breeds (Cloete *et al*., 2014). The Meatmaster is a relatively novel composite breed, which is well adapted and is selected for good fertility and growth characteristics, and is increasing in popularity (Peters *et al*., 2010). The hair sheep breeds (Dorper and Meatmaster) are regarded as early maturing breeds, while the Merino is regarded as a late maturing breed (Brand *et al*., 2018). The dual-purpose (Dohne Merino and SAMM) as well as the Dormer breeds are considered to be medium maturing breeds, relative to the previous breeds, though Cloete *et al*. (2012) has shown that Dormer lambs are early maturing relative to SAMM lambs. This diverse range of genotypes results in a number of breeds that present different growth patterns according to the selection pressures that these breeds were exposed to. Precision farming is a recent development that incorporates the use of technology in livestock farming in order to improve sustainability and profitability (Banhazi *et al*., 2012). Many producers are shifting towards intensive feedlotting systems and incorporating precision models to aid with monitoring and decision making. Thus in intensive small stock production systems, it is important to be able to predict the growth characteristics of different sheep breeds so as to anticipate what the ideal market weight should be, according to prevailing market conditions. The aim of this study was thus to determine which growth models would be most applicable in modelling the growth of wool, dual-purpose and mutton breeds that are popular in commercial sheep production systems in South Africa.

## 3.2 Material and methods

### 3.2.1 Animal management

Ethical clearance for this study was obtained from the Western Cape Department of Agriculture's departmental ethics committee (DECRA R14/110). Lambs from seven sheep breeds that are popular in South African commercial sheep production systems, were reared from birth until maturity and their growth was monitored. The breeds were Dohne Merino, Dormer, Dorper, Meatmaster, Merino, South African Mutton Merino and White Dorper. Resource flocks of 25 ewes per breed, of each of the breeds, were herded on Langgewens Research Farm in the Swartland district of the Western Cape in South Africa (coordinates: -33.276833, 18.704252). The region experiences Mediterranean climate conditions, with hot, dry, windy summers and wet winters with the majority of annual rainfall (395 mm) recorded between April and September. These resource flocks were established by acquiring sheep from local stud breeders, representing the potential of the breeds for good growth. The ewes were synchronised and mated in December, to rams from the respective breeds that were selected for high growth rates. Lambing then occurred during the month of May the following year, after mating in December five months prior.

Within 24 hours of lambing, lambs were identified and sex and birth weights were recorded. The lambs were then weighed on a weekly basis until they were one year old, when they were considered to have attained mature body weight. Pre-weaning, lambs were reared with their dams on medics pastures (*Medicago truncutula, Medicago littoralis* and *Medicago polymorpha*), and received creep feed *ad libitum* from 28 days of age until they were weaned at about 120 days of age. The creep feed (primarily formulated using wheat and full-fat canola) contained 869 g/kg total digestible nutrients, with a crude protein content of 182 g/kg, 135 g/kg fat, 84 g/kg crude fibre, 11.2 g/kg calcium and 7.4 g/kg total phosphorous. After weaning, the lambs were divided into groups of ram and ewe lambs and were reared under feedlot conditions on a pelleted finisher diet which was supplied *ad libitum*. The finisher diet (primarily containing maize, *Medicago sativa* hay and cotton seed oilcake) fed to the lambs was formulated for optimal growth, containing 708 g/kg total digestible nutrients, with a crude protein content of 159 g/kg, 10.62 MJ/kg metabolisable energy, 219 g/kg neutral detergent fibre, 26 g/kg calcium and 8.0 g/kg phosphorous. The nutrient composition of the finisher ration used in this study was formulated to meet the requirements set by the National Research Council (2017) for growing lambs.

At weaning, the lambs were vaccinated with a broad-spectrum vaccine and drenched against internal parasites, with booster vaccinations being provided at 8 months of age. The lambs were reared under these conditions to ensure maximal growth of the lambs, according to their genetic potential, without being limited by the substrate being consumed or energy for growth being lost due to movement during grazing. This is to realise uninhibited growth curves for each breed under idealised growth conditions.

Body weight data was collected from lambs from two consecutive production years (2016 and 2017). Unfortunately, the region experienced drought during this period which hindered the number lambs born and surviving the duration of the study. Over the period, 48 consecutive body weight measurements were collected from Dohne Merino (ram =11, ewe =19), Dormer (ram =13, ewe =12), Dorper (ram =13, ewe =15), Meatmaster (ram =21, ewe =16), Merino (ram =6, ewe =6), SAMM (ram =16, ewe =16) and White Dorper (ram =13, ewe =15) lambs from birth until one year of age.

### 3.2.2 Statistical analysis

The age-weight data of the lambs was analysed using SAS Enterprise Guide (SAS version 7.1) using the PROC NLIN to fit the selected growth models to the individual growth curves of the lambs from each of the breeds. The Brody, Gompertz, Logistic and Von Bertalanffy functions (Table 3.1) were fitted to the individual growth curves using the Guass-Newton iteration method with step-halving set at a maximum of 100 iterations if convergence was not achieved at a criteria of 1 x $10^{-05}$. From these individual growth curves, parameter values for each of the respective functions were determined and recorded. Individual curves that failed to converge were regarded as outliers and the parameter values for the model were ignored.

The parameter values for each of the respective model functions were compared between the breed groups by analysis of variance (ANOVA) using the general linear models (GLM) procedure of SAS enterprise guide. The influence of the main effects of breed and sex (ram or ewe), as well as the interaction between these effects, on the parameter values of the various models were evaluated. Differences in model parameter values between the breed-sex production groups were regarded to be significant at the 5% confidence level ($P \leq 0.05$). The model parameter means were expressed as least square means with respective standard errors. In order for models to be compared, to determine which function is best suited to describe the growth of the various production groups, the root mean square error (RMSE), Akaike information criterion (AIC) and $R^2$ coefficients of determination between observed and expected values were determined. The AUTOREG procedure of SAS enterprise guide was used to determine the RMSE, AIC and $R^2$ values of the various models fitted to the respective production groups.

**Table 3.1** Description of functions used to model the growth of sheep in this study.

| Model | Function | Reference |
|---|---|---|
| Brody | $W_t = A(1 - Be^{-kt})$ | Brody, 1945 |
| Gompertz | $W_t = Ae^{-e^{-k(t-C)}}$ | Emmans, 1989 |
| Logistic | $W_t = A/(1 + Be^{-kt})$ | Nelder, 1961 |
| Von Bertallanffy | $W_t = A(1 - Be^{-kt})^3$ | Von Bertalanffy, 1957 |

$W_t$ represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight. *B* denotes the proportion of live weight to be gained after birth, while *k* represents the maturation rate.
In the Gompertz function *C* represents age at the inflection point.

## 3.3 Results and discussion

The parameter means with standard errors (S.E.) for various growth models fitted to the different breeds are presented in Tables 3.2-3.5. Interactions were observed between the effects of breed and sex ($P \leq 0.05$) for most of the model parameter comparisons. The *A* parameter of the Brody model (Table 3.2), indicating the asymptotic mature weights of the sheep, had noticeably high parameter values for all of the production groups. In some cases the predicted asymptotic weight differs with as much as 47-86 kg between rams and ewes of the same breed. These weights also tend to be exaggerated; as the mature weights for Dohne Merino sheep tend to be around 70 kg for ewes and 115 kg for rams (predicted 116 kg and 202 kg, respectively), and that of SAMM sheep being 75 kg for ewes and 120 kg for rams (predicted 165 kg and 247 kg, respectively) (Terra vino stud, Mariendahl Experimental farm, 2018). Cloete (1994) also reported live weights of 50 kg for Merino ewes and 74 kg for SAMM and Dormer ewes at an age of 5-6 years. Cloete *et al*. (2007) mated mature Dorper ewes at a live weight of ~63 kg (predicted 169 kg). The weights of the ewes reported by Cloete (1994) and Cloete *et al*. (2007) are lower than that observed in the present study; however, it must be remembered the rearing conditions of the ewes in the studies differed. Nonetheless, it is still clear that the asymptotic weights derived by the Brody model greatly exceed the expected norms of the various breeds. This does suggest possible inaccuracies in prediction when using the Brody function to model the growth of the breeds evaluated in this study. Another limitation of the Brody model is that its inflection point cannot be determined, due to the prerequisite of the function being greater than zero not being satisfied by any value of age (*t*) (Goshu & Koya, 2013).

**Table 3.2** Comparison of model parameters (± S.E.) estimated for the Brody model [$W_t = A(1 - Be^{-kt})$] fitted to rams and ewes of various sheep breed types.

| Breed | Sex | Brody parameters | | |
|---|---|---|---|---|
| | | ***A*** | ***B*** | ***k*** |
| Dohne Merino | Ewe | 116.18$^{c}$ ± 19.11 | 1.0042$^{bcd}$ ± 0.0038 | 0.0034$^{a}$ ± 0.0002 |
| | Ram | 202.08$^{abc}$ ± 25.11 | 1.0106$^{abcd}$ ± 0.0050 | 0.0022$^{abc}$ ± 0.0003 |
| Dormer | Ewe | 252.85$^{ab}$ ± 24.04 | 1.0166$^{a}$ ± 0.0048 | 0.0017$^{b}$ ± 0.0003 |
| | Ram | 300.21$^{a}$ ± 24.04 | 1.0149$^{ab}$ ± 0.0048 | 0.0016$^{b}$ ± 0.0003 |
| Dorper | Ewe | 169.63$^{abc}$ ± 22.26 | 1.0014$^{cd}$ ± 0.0044 | 0.0027$^{abc}$ ± 0.0003 |
| | Ram | 184.91$^{abc}$ ± 27.76 | 1.0052$^{abcd}$ ± 0.0055 | 0.0028$^{abc}$ ± 0.0003 |
| Meatmaster | Ewe | 188.73$^{abc}$ ± 21.50 | 0.9993$^{abc}$ ± 0.0043 | 0.0021$^{b}$ ± 0.0003 |
| | Ram | 252.18$^{ab}$ ± 18.17 | 1.0099$^{abc}$ ± 0.0036 | 0.0018$^{b}$ ± 0.0002 |
| Merino | Ewe | 135.86$^{bc}$ ± 34.00 | 0.9943$^{de}$ ± 0.0043 | 0.0028$^{abc}$ ± 0.0004 |
| | Ram | 144.06$^{abc}$ ± 37.24 | 1.0099$^{abcde}$ ± 0.0074 | 0.0032$^{bc}$ ± 0.0004 |
| SA Mutton Merino | Ewe | 165.25$^{abc}$ ± 25.11 | 1.0003$^{cde}$ ± 0.0050 | 0.0025$^{abc}$ ± 0.0003 |
| | Ram | 246.66$^{ab}$ ± 23.10 | 0.9998$^{cde}$ ± 0.0046 | 0.0020$^{b}$ ± 0.0003 |
| White Dorper | Ewe | 149.16$^{abc}$ ± 22.26 | 0.9879$^{e}$ ± 0.0044 | 0.0027$^{abc}$ ± 0.0003 |
| | Ram | 164.29$^{abc}$ ± 23.10 | 1.0036$^{abcd}$ ± 0.0046 | 0.0026$^{bc}$ ± 0.0003 |

$W_t$ represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight. *B* denotes the proportion of live weight to be gained after birth, while *k* represents the maturation rate.

$^{a\text{-}e}$ Column means with different superscripts vary ($P \leq 0.05$).

Although the main form of the Gompertz model is widely used throughout literature (Malhado *et al*., 2009; Goshu & Koya, 2013; Moreira *et al*., 2016), however, for this study the form utilised by Emmans (1989) was selected due to the biological interpretation of the model parameters in this form of the function. As with the other models, *A* represents the asymptotic mature weight of the sheep and *k* represents the coefficient of growth/ maturation, while *C* represents the age at maximum growth rate or simply the inflection point. When age (*t*) is equal to *C*, the weight of the animal can be determined by dividing *A* by the Eulers constant or exponential term (i.e. *A*/*e*) (Emmans, 1989). The asymptotic weight parameter differed between the production groups ($P \leq 0.05$), with the highest parameter values being observed for SAMM and Dormer rams (129.52 and 125.26, respectively) (Table 3.3). This was followed by Dohne Merino, Meatmaster and Dorper rams which was tailed by Dormer, Dorper, Meatmaster, SAMM and White Dorper ewes and Merino and White Dorper rams. In turn, the lowest *A* parameters values were obtained by Merino and Dohne Merino ewes (91.99 and 81.34, respectively). No differences ($P > 0.05$) were observed between the production groups for the Gompertz *k* parameter, with an average parameter value of 0.0095. The Dormer rams presented the highest *C* parameter value (142.35) which was significantly higher than that of

White Dorper rams (113.29), Merino rams (105.75) and the lowest value being obtained by Dohne Merino ewes (105.30). The remaining production groups did not differ from each other (~125.78) (*P* >0.05). The implications of these results show that Dormer and SAMM rams have the heaviest mature weights and also present maximal growth at a later stage (higher *C* values), while the Dohne Merino ewes have the lightest mature weights and attain maximal growth rates as early as 105 days of age. From the results in Table 3.3, it would seem that a positive correlation may exist between the *A* and *C* parameters; indicating that an increase in mature weight would result in the inflection point being attained at a later age. This trend may warrant further insight, as previous results have shown significant negative correlations between *A* and *k,* which suggest that selection for higher mature weights, result in lower maturation rates (Bathaei & Leroy, 1998; Malhado *et al*., 2009). This apparent relationship between *A* and *C* can more simply be expressed as early maturing animals have a lower mature weight than late maturing animals, and thus attain maximum growth rates at an earlier age (Owens *et al*., 1993). This is illustrated in Table 3.3, where for example, the *A* (125.26) and *C* (142.35) parameter values of Dormer rams are both respectively higher than that of White Dorper rams (101.87 and 113.29, respectively). This shows that White Dorper rams mature earlier than the Dormer rams, by attaining the inflection point of their respective curve at an earlier age and growing to a lighter mature weight. Again, this relationship can be seen between ewes and rams of the same breed, owing to the fact that female animals mature earlier than their male counterparts.

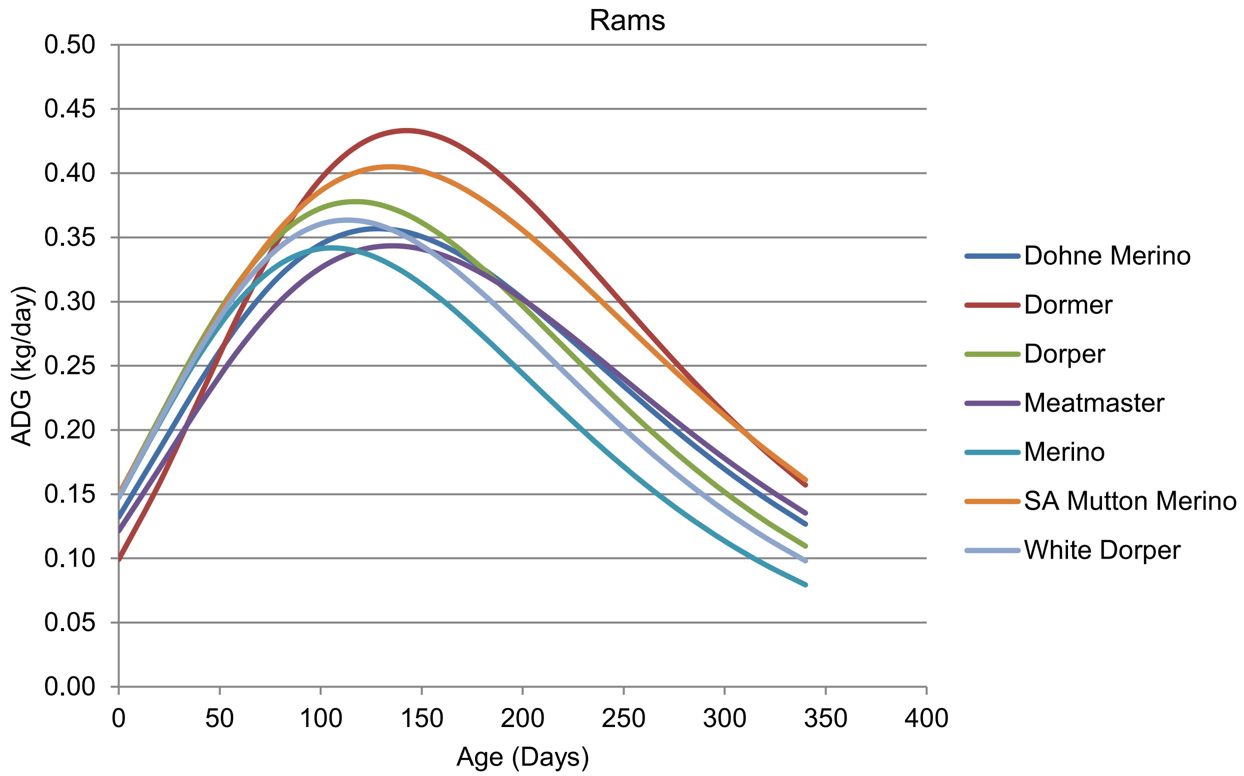
**Table 3.3** Comparison of model parameters (± S.E.) estimated for the Gompertz model [$W_t = Ae^{-e^{-k(t-C)}}$] fitted to rams and ewes of various sheep breed types.

| Breed | Sex | Gompertz parameters | | |
|---|---|---|---|---|
| | | ***A*** | ***k*** | ***C*** |
| Dohne Merino | Ewe | $81.34^{e}$ ± 3.08 | 0.0100 ± 0.0004 | $105.30^{c}$ ± 4.56 |
| | Ram | $108.97^{bc}$ ± 4.04 | 0.0089 ± 0.0005 | $128.39^{abc}$ ± 6.00 |
| Dormer | Ewe | $105.88^{cd}$ ± 3.87 | 0.0094 ± 0.0005 | $137.90^{ab}$ ± 5.74 |
| | Ram | $125.26^{ab}$ ± 3.72 | 0.0094 ± 0.0004 | $142.35^{a}$ ± 5.52 |
| Dorper | Ewe | $96.67^{cde}$ ± 3.46 | 0.0093 ± 0.0004 | $117.21^{abc}$ ± 5.14 |
| | Ram | $108.13^{bcd}$ ± 4.47 | 0.0095 ± 0.0005 | $117.08^{abc}$ ± 6.63 |
| Meatmaster | Ewe | $93.81^{cde}$ ± 3.35 | 0.0083 ± 0.0004 | $131.09^{ab}$ ± 4.97 |
| | Ram | $108.56^{bc}$ ± 2.93 | 0.0086 ± 0.0004 | $135.39^{ab}$ ± 4.34 |
| Merino | Ewe | $83.68^{de}$ ± 5.47 | 0.0089 ± 0.0007 | $114.73^{abc}$ ± 8.12 |
| | Ram | $91.99^{cde}$ ± 5.47 | 0.0101 ± 0.0007 | $105.75^{bc}$ ± 8.12 |
| SA Mutton Merino | Ewe | $98.94^{cde}$ ± 4.04 | 0.0095 ± 0.0005 | $117.42^{abc}$ ± 6.00 |
| | Ram | $129.52^{a}$ ± 3.35 | 0.0085 ± 0.0004 | $134.47^{ab}$ ± 4.97 |
| White Dorper | Ewe | $91.92^{cde}$ ± 3.46 | 0.0085 ± 0.0004 | $115.99^{abc}$ ± 5.14 |
| | Ram | $101.87^{cd}$ ± 3.72 | 0.0097 ± 0.0004 | $113.29^{bc}$ ± 5.52 |

$W_t$ represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight, *k* represents the maturation rate, while *C* represents age at the inflection point in days.

$^{a-e}$ Column means with different superscripts vary ($P \leq 0.05$).

While modelling the growth curve of sheep gives an indication of the body weight of sheep at a given age, it is also important to be aware of the changes in growth rate of the growing lambs. By differentiating the Gompertz growth curve, the change in slope (change in growth rate) can be observed for rams and ewes of the respective breeds (Figure 3.1). As mentioned, the *C* parameter represents the inflection point of the growth curve. This is also the point at which maximal growth rates are attained. Lambs typically reach this point of their growth soon after weaning (100-140 days of age) under optimal growth conditions, with no complimentary growth taking place. This also coincides with the age that lambs are generally introduced to feedlot finishing. In Figure 3.1 it can be seen that the maximum growth rates, at the inflection points, estimated for Dormer, SAMM, Dorper, White Dorper, Dohne Merino, Meatmaster and Merino ram lambs are approximately 0.430, 0.400, 0.370, 0.360, 0.350, 0.340 and 0.340 kg/day, respectively. The approximate maximum growth rates estimated for ewe lambs from Dormer, SAMM, Dorper, Dohne Merino, White Dorper, Meatmaster and Merino breeds are 0.360, 0.340, 0.330, 0.300, 0.290, 0.280 and 0.270 kg/day, respectively (Figure 3.1). Due to the sexual dimorphism and heavier mature weights obtained by rams, it is expected that they will also exhibit higher growth rates than ewes (Butterfield, 1988; Owens *et al*., 1993). In lamb finishing systems, producers aim for a minimum growth rate of 0.300 kg/day to ensure the required efficiency of production. From Figure 3.1 it can be seen that growth rates of Merino rams decreases below this threshold after ~160 days of age, ~200 days for Dohne Merino, Dorper, Meatmaster and White Dorper breeds, while the growth rates of the larger framed Dormer and SAMM ram lambs cross this threshold after ~240 days of age. In ewe lambs, the Dohne Merino, Meatmaster, Merino and White Dorper breeds do not meet these average growth rates in their growth. The growth rates of SAMM and Dorper ewes then decrease below the desired 0.300 kg/day threshold after ~180 days of age, while Dormers cross this threshold value later (~220 days of age). In order for optimum production to be achieved, it is recommended that producers take these trends in growth rate into consideration



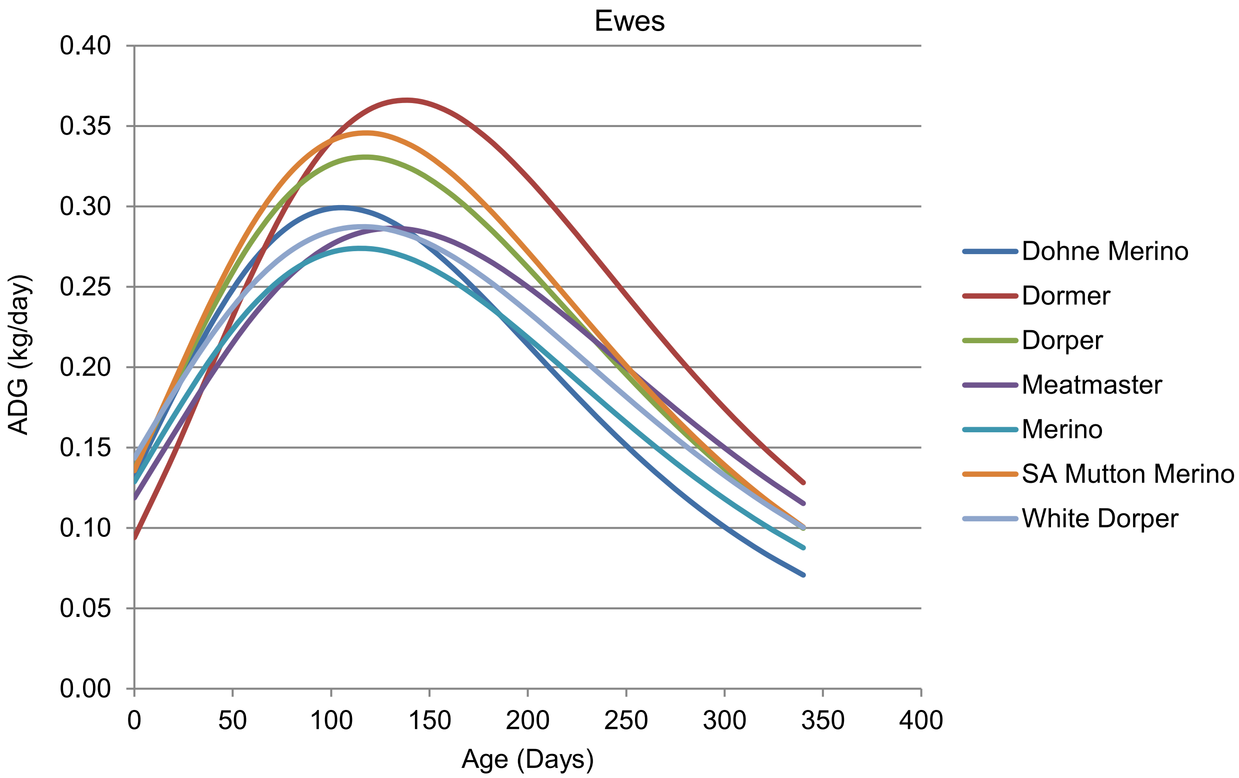




**Figure 3.1** Illustration of the change of the average daily gain (ADG) of ram and ewe lambs of the respective breeds, as predicted by differentiation of the Gompertz growth curve ($W_t = Ae^{-e^{-k(t-C)}}$]).

The asymptotic weight parameter *A* of the Logistic model followed a similar pattern to that of the Gompertz model (Table 3.4), with the highest parameter values again being obtained by SAMM and Dormer rams (115.87 and 112.40, respectively). The *A* values of Dohne Merino, Dorper and Meatmaster rams as well as Dormer ewes followed these production groups with an average parameter estimate of 98.52. While not differing from the previous groups ($P$ >0.05), the Dorper, Meatmaster, SAMM and White Dorper ewes as well Merino and White Dorper rams clustered together in the next ranking of *A* values (~86.63). The Merino and Dohne Merino ewes again presented the lowest *A* parameter estimated by the logistic model (77.41 and 76.37, respectively). Although the parameter estimates follows a similar trend between the production groups, it is observed that the asymptotic mature weights estimated by the logistic model are noticeably lower than those estimated by the Gompertz model (Table 3.3). With regard to the *B* parameter estimates of the Logistic model, Dormer rams presented a higher value ($P$ ≤0.05) than Merino and White Dorper ewes (15.413 *vs*. 7.445 and 7.898, respectively); however, the remaining production groups did not differ from each other ($P$ >0.05). The values of the maturation rate parameter *k* did not vary between most of the production groups ($P$ >0.05), with the exception of Merino rams having higher maturation rates than White Dorper ewes (0.0179 *vs*. 0.0139, respectively; $P$ ≤0.05). It has been shown that *k* parameter estimates are usually higher in males and single born lambs (Bathaei & Leroy*.,* 1996), with higher *k* values indicating that faster growth takes place (Malhado *et al*., 2009). Hence, Merino rams present faster growth than White Dorper ewes, however, these parameter values do not differ from the other groups implying that, overall, maturation rates are fairly similar. From the Gompertz function, it was easy to recognise the point of inflection on the growth from the model function. In order to determine the point of inflection of the Logistic curve, differentiation of the curve is necessary to determine the point of maximal growth. Goshu & Koya (2013) showed that the weight of the animal at the point of inflection of the Logistic growth curve can simply be calculated as half of the mature weight *A*. Further growth beyond this point will be realised with declining growth rates as the sheep nears maturity.

**Table 3.4** Comparison of model parameters (± S.E.) estimated for the Logistic model [$W_t = A/(1 + Be^{-kt})$] fitted to growth curves of rams and ewes of various sheep breed types.

| Breed | Sex | Logistic parameters | | |
|---|---|---|---|---|
| | | ***A*** | ***B*** | ***k*** |
| Dohne Merino | Ewe | $76.37^{e}$ ± 2.58 | $8.953^{ab}$ ± 1.002 | $0.0156^{ab}$ ± 0.0005 |
| | Ram | $99.70^{bc}$ ± 3.39 | $10.699^{ab}$ ± 1.317 | $0.0146^{ab}$ ± 0.0007 |
| Dormer | Ewe | $96.86^{bcd}$ ± 3.24 | $13.177^{ab}$ ± 1.261 | $0.0153^{ab}$ ± 0.0007 |
| | Ram | $112.40^{ab}$ ± 3.11 | $15.413^{a}$ ± 1.212 | $0.0154^{ab}$ ± 0.0006 |
| Dorper | Ewe | $86.49^{cde}$ ± 2.90 | $9.060^{ab}$ ± 1.128 | $0.0154^{ab}$ ± 0.0006 |
| | Ram | $99.29^{bc}$ ± 3.74 | $8.869^{ab}$ ± 1.456 | $0.0150^{ab}$ ± 0.0008 |
| Meatmaster | Ewe | $84.23^{cde}$ ± 2.81 | $9.657^{ab}$ ± 1.092 | $0.0139^{ab}$ ± 0.0006 |
| | Ram | $98.24^{bc}$ ± 2.45 | $11.807^{ab}$ ± 0.953 | $0.0146^{ab}$ ± 0.0005 |
| Merino | Ewe | $77.41^{de}$ ± 4.58 | $7.445^{b}$ ± 1.783 | $0.0139^{ab}$ ± 0.0009 |
| | Ram | $80.51^{cde}$ ± 4.58 | $8.797^{ab}$ ± 1.783 | $0.0179^{a}$ ± 0.0009 |
| SA Mutton Merino | Ewe | $90.86^{cde}$ ± 3.39 | $9.502^{ab}$ ± 1.317 | $0.0152^{ab}$ ± 0.0007 |
| | Ram | $115.87^{a}$ ± 2.81 | $11.722^{ab}$ ± 1.092 | $0.0146^{ab}$ ± 0.0006 |
| White Dorper | Ewe | $83.94^{cde}$ ± 2.90 | $7.898^{b}$ ± 1.128 | $0.0139^{b}$ ± 0.0006 |
| | Ram | $93.72^{cd}$ ± 3.11 | $9.276^{ab}$ ± 1.212 | $0.0157^{ab}$ ± 0.0006 |

$W_t$ represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight. *B* denotes the proportion of live weight to be gained after birth, while *k* represents the maturation rate.

$^{a-e}$ Column means with different superscripts vary ($P$ ≤0.05).

The Von Bertalanffy model was also fitted to the growth curves of the various sheep production groups and the parameter estimates were compared (Table 3.5). The differences in the *A* parameter followed a similar trend to that outlined by the Gompertz and Logistic functions, although, the Von Bertalanffy model estimated higher asymptotic mature weights than those predicted by the Gompertz and Logistic models. Both Dormer groups presented higher *B* parameter estimates than White Dorper ewes (~0.820 *vs*. 0.637, respectively; *P* ≤0.05). The remaining production groups did not present any significant differences between them with regard to the *B* parameter. The *k* maturation rate parameter similarly did not vary between the sheep production groups (*P* >0.05).

**Table 3.5** Comparison of model parameters (± S.E.) estimated for the Von Bertalanffy model [$W_t = A(1 - Be^{-kt})^3$] fitted to growth curves of ram and ewe lambs from various sheep breed types.

| Breed | Sex | Von Bertalanffy parameters | | |
|---|---|---|---|---|
| | | *A* | *B* | *k* |
| Dohne Merino | Ewe | 85.07$^{e}$ ± 3.79 | 0.669$^{ab}$ ± 0.026 | 0.0080 ± 0.0003 |
| | Ram | 116.18$^{bcd}$ ± 4.99 | 0.710$^{ab}$ ± 0.034 | 0.0070 ± 0.0004 |
| Dormer | Ewe | 112.96$^{bcd}$ ± 4.78 | 0.824$^{a}$ ± 0.033 | 0.0073 ± 0.0004 |
| | Ram | 136.72$^{ab}$ ± 4.59 | 0.815$^{a}$ ± 0.032 | 0.0070 ± 0.0004 |
| Dorper | Ewe | 102.29$^{cde}$ ± 4.42 | 0.686$^{ab}$ ± 0.030 | 0.0075 ± 0.0004 |
| | Ram | 112.36$^{bcd}$ ± 5.85 | 0.677$^{ab}$ ± 0.040 | 0.0075 ± 0.0005 |
| Meatmaster | Ewe | 101.91$^{cde}$ ± 4.14 | 0.671$^{ab}$ ± 0.029 | 0.0063 ± 0.0004 |
| | Ram | 117.00$^{bc}$ ± 3.61 | 0.726$^{ab}$ ± 0.025 | 0.0066 ± 0.0004 |
| Merino | Ewe | 88.42$^{de}$ ± 6.76 | 0.643$^{ab}$ ± 0.047 | 0.0071 ± 0.0006 |
| | Ram | 106.85$^{cde}$ ± 6.76 | 0.687$^{ab}$ ± 0.047 | 0.0077 ± 0.0006 |
| SA Mutton Merino | Ewe | 105.18$^{cde}$ ± 4.99 | 0.711$^{ab}$ ± 0.034 | 0.0076 ± 0.0004 |
| | Ram | 141.32$^{a}$ ± 4.14 | 0.667$^{ab}$ ± 0.029 | 0.0064 ± 0.0004 |
| White Dorper | Ewe | 98.23$^{cde}$ ± 4.27 | 0.637$^{b}$ ± 0.029 | 0.0067 ± 0.0004 |
| | Ram | 108.18$^{cd}$ ± 4.59 | 0.685$^{ab}$ ± 0.032 | 0.0076 ± 0.0004 |

$W_t$ represents body weight of the sheep at time *t*. *A* denotes the asymptotic mature weight. *B* denotes the proportion of live weight to be gained after birth, while *k* represents the maturation rate.

$^{a-e}$ Column means with different superscripts vary ($P \leq 0.05$).

In order to determine which of the four models tested would be most appropriate in describing the growth of the various production groups; the models fit statistics were determined (Table 3.6). The model fit statistics that were used included the root mean square errors (RMSE), Akaike information criteria (AIC) and $R^2$ coefficients of determination between the observed and expected weights. When comparing the RMSE and AIC values between the various models, a lower value will indicate a better fit for the data, while a higher $R^2$ percentage indicates that a greater portion of the data is accounted for by the model. In all of the cases in this study, the Brody model presented the highest RMSE and AIC values, and while still presenting high $R^2$ values (greater than 94.0), relatively lower $R^2$ compared to the other models tested. This can be expected due to the uncharacteristically high *A* parameter value estimates (Table 3.2). This confirms that the Brody function is not suited to describe the data of the growth exhibited by the breeds in this study.

The logistic models seemed to best fit the data, presenting the lowest values for RMSE and AIC, while presenting the highest $R^2$ percentages in each of the production groups modelled (Table 3.6). The Gompertz and Von Bertalanffy functions displayed respectively higher RMSE and AIC values and lower $R^2$ values than that of the logistic function in the various production groups. However, the $R^2$ values ranged within a single percent between these three models fitted to the various production groups. This implies that the Gompertz, Logistic or Von Bertalanffy models can be used to describe the growth of the South African breeds under optimal conditions, though the Logistic model does present the upper hand in statistical accuracy. Throughout literature, it has been seen that models vary in accuracy according to the breed and situation that is being modelled. Hossein-Zadeh (2015) found that the Richards function best described the fit of Shall sheep. The Richards function was deemed unsuitable in modelling the growth of lambs in this analysis, as a majority of the iterations failed to converge. Bathaei & Leroy (1998) found success in using the Brody model to describe growth of Mehraban sheep. Both of the above cases relied on a few static recordings per animal from a large population. Other studies that used continuous body weight measurements during the study periods with fewer animals showed that the Gompertz, Logistic and Von Bertalanffy models are most suited to describe these datasets (Keskin *et al*., 2009; Malhado *et al*., 2009; Moreira *et al*., 2016). The dataset used in this study also consisted of continuous measurements and also showed that the Gompertz, Logistic and Von Bertalanffy functions were most applicable to model the growth of the various sheep breeds.

**Table 3.6** Evaluation of Brody, Gompertz, Logistic and Von Bertalanffy models fitted to growth curves of ram and ewe lambs from various South African sheep breeds using root mean square error (RMSE), Akaike's information criterion (AIC) and the $R^2$ coefficient between the observed and expected curves.

| **Breed** | **Model** | **Ewes** | | | **Rams** | | |
|---|---|---|---|---|---|---|---|
| | | **RMSE** | **AIC** | **$R^2$** | **RMSE** | **AIC** | **$R^2$** |
| Dohne Merino | Brody | 6.471 | 197.871 | 94.8 | 8.459 | 215.168 | 95.5 |
| | Gompertz | 5.199 | 185.212 | 95.7 | 6.560 | 200.108 | 96.4 |
| | Logistic | 4.747 | 179.824 | 96.1 | 5.949 | 194.299 | 96.6 |
| | Von Bertalanffy | 5.458 | 188.025 | 95.6 | 6.931 | 203.396 | 96.2 |
| Dormer | Brody | 8.569 | 213.794 | 95.7 | 10.157 | 221.887 | 95.6 |
| | Gompertz | 6.463 | 197.377 | 96.7 | 7.553 | 204.436 | 96.6 |
| | Logistic | 5.881 | 191.864 | 96.8 | 6.839 | 198.703 | 96.8 |
| | Von Bertalanffy | 6.793 | 200.205 | 96.5 | 7.988 | 207.681 | 96.5 |
| Dorper | Brody | 7.521 | 202.372 | 95.0 | 7.621 | 208.829 | 94.9 |
| | Gompertz | 5.989 | 189.546 | 96.0 | 6.749 | 195.858 | 95.9 |
| | Logistic | 5.367 | 187.215 | 96.1 | 6.099 | 190.060 | 96.2 |
| | Von Bertalanffy | 6.299 | 192.335 | 95.8 | 6.881 | 197.100 | 95.7 |
| Meatmaster | Brody | 7.106 | 199.240 | 95.4 | 8.489 | 210.305 | 95.6 |
| | Gompertz | 5.565 | 185.344 | 96.3 | 6.503 | 194.995 | 96.5 |
| | Logistic | 5.014 | 179.383 | 96.6 | 5.898 | 189.398 | 96.7 |
| | Von Bertalanffy | 5.896 | 188.644 | 96.2 | 6.870 | 198.162 | 96.4 |
| Merino | Brody | 6.502 | 197.358 | 95.1 | 7.486 | 202.251 | 94.8 |
| | Gompertz | 5.135 | 180.547 | 95.9 | 5.978 | 189.492 | 95.7 |
| | Logistic | 4.628 | 174.565 | 96.2 | 5.337 | 182.883 | 95.2 |
| | Von Bertalanffy | 5.418 | 183.618 | 95.7 | 6.607 | 194.885 | 95.7 |
| SA Mutton Merino | Brody | 7.814 | 204.899 | 95.2 | 9.980 | 218.751 | 95.5 |
| | Gompertz | 6.206 | 191.752 | 96.0 | 7.769 | 204.579 | 96.4 |
| | Logistic | 5.623 | 186.043 | 96.3 | 7.004 | 198.622 | 96.6 |
| | Von Bertalanffy | 6.543 | 193.923 | 95.9 | 7.823 | 202.981 | 96.0 |
| White Dorper | Brody | 6.906 | 197.435 | 95.1 | 8.198 | 207.525 | 95.2 |
| | Gompertz | 5.536 | 184.87 | 96.1 | 6.472 | 193.857 | 95.9 |
| | Logistic | 4.989 | 178.888 | 96.3 | 5.870 | 188.250 | 96.1 |
| | Von Bertalanffy | 5.858 | 188.128 | 95.9 | 6.831 | 196.963 | 95.8 |

From Figures 3.2 and 3.3, it can be seen that the three growth models that were found to appropriately describe the respective growth curves, closely resemble each other, as well as the selected breed means. While the Logistic model has been shown to be the best option to describe the growth of the various production groups by having the lowest RMSE, AIC and highest $R^2$ values, visual inspection of the graphical representations does show that the model may have some shortcomings. In most cases, the Logistic model seems to overestimate birthweight and early growth up until around 50 days of age. It is thus suggested, that the Gompertz or Von Bertalanffy models should rather be used to predict the weights of lambs under 50 days of age. It is also observed that the models tend to overestimate the weights of Dorper sheep by 7 kg for ewes and 5 kg for rams around 240 days of age. While the models predict slightly higher year old weights in some cases, although not greatly exaggerated, it is noticeable that there is a large variation in the year old weights predicted for Merino rams (Figure 3.3). Both the Gompertz and Logistic curves underestimate the weights at this point, while the Von Bertalanffy model does give a better representation. Yearling Merino ram weights are expected to be 60-70 kg in pastoral systems (Cloete *et al*., 2001; Hötzel *et al*., 2003), unlike the high body weights achieved in this study under optimal growth conditions. The growth curves of more individuals of Merino rams may need to be collected to improve the accuracy of the models; although the combination of the three models do provide upper and lower limits for any variation within this breed group (79.5-94.1 kg) around this age. While the models for the various production groups in Tables 3.3-3.5 depict that there are differences in the growth and mature weights between the sexes, Figures 3.2 and 3.3 do provide a better visual interpretation of the higher growth (or maturation) rates and heavier body weights achieved by rams than ewes of the same breed.

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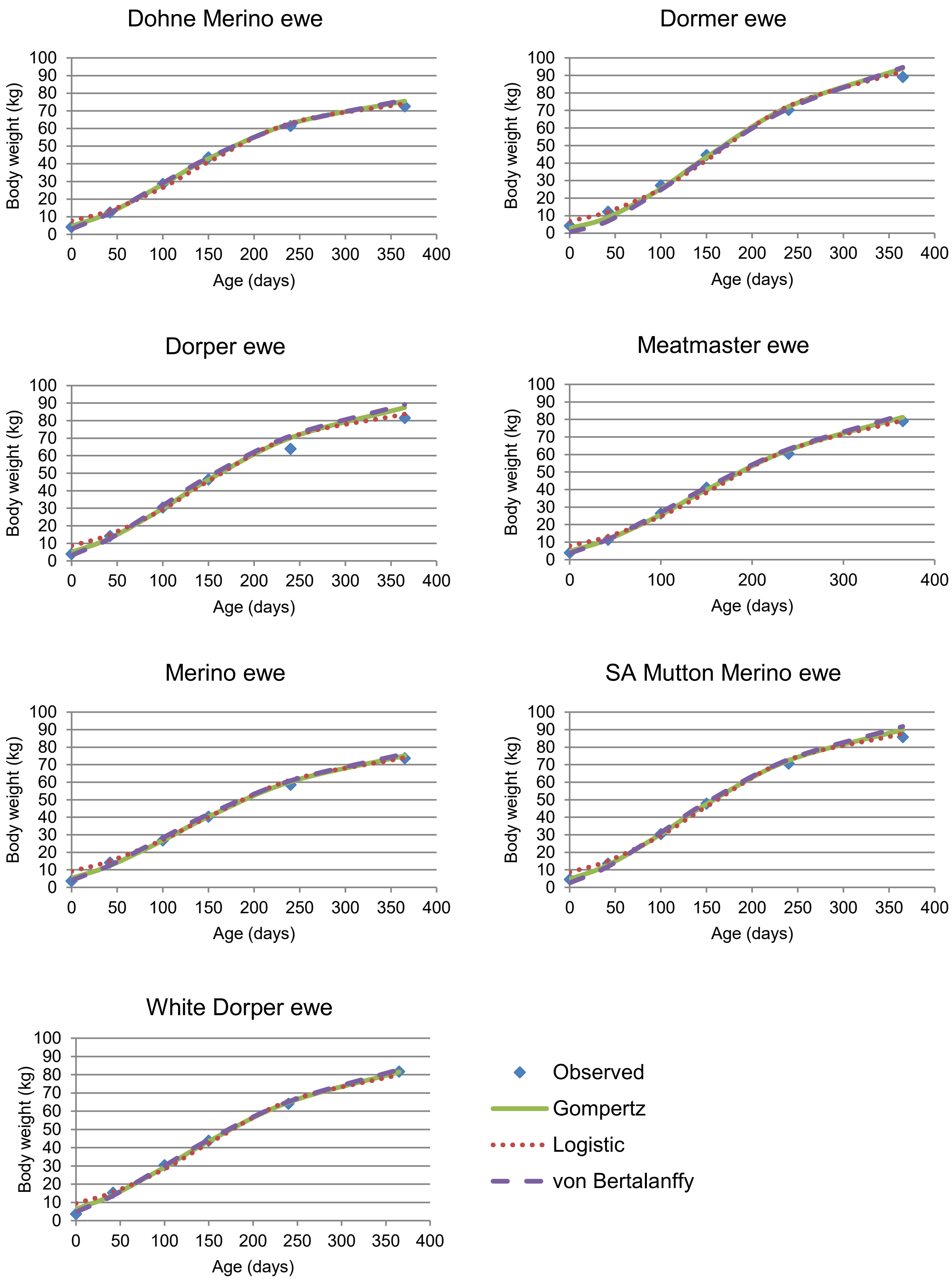


**Figure 3.2** The Gompertz, Logistic and Von Bertalanffy models fitted to the growth curves of various ewe breeds.

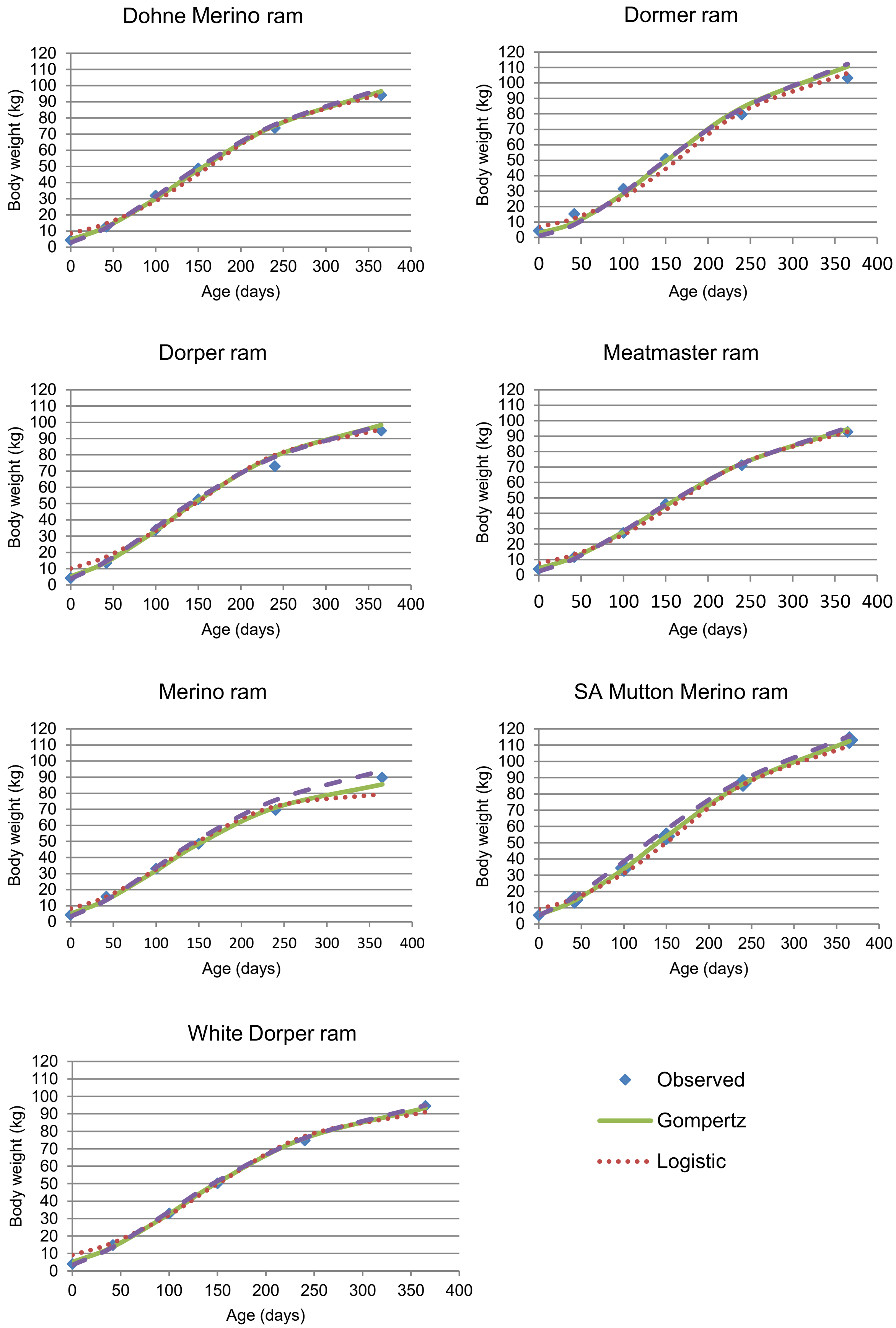


**Figure 3.3** The Gompertz, Logistic and Von Bertalanffy models fitted to the growth curves of various ram breeds.

With regards to the growth patterns displayed by the different sheep production groups, generally it was seen that rams displayed higher maturation rates and mature weights than respective females of the same breed. These differences in growth are expected due to the sexual dimorphism between rams and ewes, with greater growth being experienced by rams and maturity being realised relatively earlier by ewes (Butterfield, 1988; Lopez *et al*., 2018). The breeds in present study were reared under optimal conditions, so as to allow uninhibited growth according to the potential of the breeds. The Dormer, which is regarded as a terminal sire breed (Zishiri *et al*., 2014), and the SAMM, which is a dual-purpose breed mainly reared for meat production, displayed the heaviest mature weights. Cloete *et al.* (2012) showed that compared to wool and other dual-purpose breeds, SAMM and Dormers do present heavier weights at slaughter, due to their higher growth rates and larger body size. These breeds have been bred, selecting for heavy body weights, with large frames so as to produce large well-rounded carcasses. The Dorper, White Dorper and Meatmaster are composite hair sheep breeds reared for meat production on extensive arid regions. The Dorper breeds are renowned for their early maturing nature and high levels of fat deposition at a young age (Schoeman, 2000; Brand *et al.,* 2018). The Meatmaster is considered as a fat-tailed breed with a strong influence of the indigenous Damara breed which, similar to the Dorper, also shows early physiological maturing characteristics (Almeida, 2011). The Merino is primarily a wool producing breed, and can therefore be expected to exhibit slower growth and lower body weights than other breeds (Brand *et al*., 2017). The Dohne Merino, which is a dual-purpose composite breed derived from the South African Merino and German Mutton Merino, produces high quality wool, while still exhibiting desirable growth characteristics (Cloete *et al*., 2001). The weights and growth of the Dohne Merino ewes tended to resemble that of the Merino, however, the growth patterns and weights of the Dohne Merino rams tended to resemble that of the meat breeds. These patterns thus reflect the characteristics of the parent breeds that were used to develop the Dohne Merino breed.

With the appropriate application of the mathematical functions used to describe the various growth curves of the breeds investigated, a model can be developed to simulate lamb growth. This model can be incorporated in precision livestock rearing systems to allow producers to run simulations that will predict the growth of the various sheep breeds at certain stages. These predictions can then be used to set a benchmark that can be used to make comparisons as well as to determine optimal rearing times, slaughter ages and weights.

## 3.4 Conclusion

The Gompertz, Logistic and Von Bertalanffy models were found to be suitable in modelling the growth of the production groups of the various breed types in this study and can be applied with reasonable accuracy. The Logistic model was found to be the most appropriate model in describing the growth curve of the lambs, though care should be taken in interpreting the curves as this model tended to overestimate the growth of lambs under 50 days of age. Differentiation of the Gompertz growth curves provided insight into the change of growth rate of the growing lambs from the various production groups, as well as gives an indication of the maximum growth rates that can be attained at the inflection point of the curve. These models present the growth of the respective breeds under optimal growth conditions and are ideal for predicting the growth of intensively finished slaughter lambs.

## References

Almeida, A.M., 2011. The Damara in the context of Southern Africa fat-tailed sheep breeds. Trop. Anim. Health. Prod. 43, 1427-1441.

Banhazi, T.M., Lehr, H., Black, J.L., Crabtree, H., Schofield, P., Tscharke, M., Berckmans, D., 2012. Precision livestock farming: an international review of scientific and commercial aspects. Int. J. Agric. & Biol. Eng. 5, 1-9.

Bathaei, S.S., Leroy, P.L.,1996. Growth and mature weight of Mehraban Iranian fat-tailed sheep. Small Rumin. Res. 22, 155-162.

Bathaei, S.S., Leroy, P.L., 1998. Genetic and phenotypic aspects of the growth curve characteristics in Mehraban Iranian fat-tailed sheep. Small Rumin. Res. 29, 261-269.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci. 47, 26-33.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci. 48, 477-488.

Brody, S., 1945. Bioenergetics and growth; with special reference to the efficiency complex in domestic animals. Reinhold publications, New York.

Butterfield, R.M., 1988. New concept of sheep growth. The Department of Veterinary Anatomy, University of Sydney.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. Meat Sci. 91, 318-324.

Cloete, S.W.P., 1994. Rearing performance of Merino, SA Mutton Merino and Dormer ewes in relation to live mass, reproduction and pelvic dimensions. J. S. Afr. Vet. Assoc. 65, 10-17.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V., 2001. Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric. 41, 145-153.

Cloete, J.J.E., Cloete, S.W.P., Olivier, J.J., Hoffman, L.C., 2007. Terminal crossbreeding of Dorper ewes to Ile de France, Merino Landsheep and SA Mutton Merino sires: Ewe production and lamb performance. Small Rumin. Res. 69, 28-35.

Cloete, S.W.P., Olivier, J.J., Sandenbergh, L., Snyman, M.A., 2014. The adaption of the South Africa sheep industry to new trends in animal breeding and genetics: A review. S. Afr. J. Anim. Sci. 44, 307-321.

Department of Agriculture, Forestry and Fisheries, 2018. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63. (https://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202018.pdf)

Emmans, G.C., 1989. The growth of turkeys. In: C. Nixen and T.C. Grey (eds.) Recent advances in turkey science. Butterworths, London, UK, pp 135-165.

Fitzhugh, H.A., 1976. Analysis of growth curves and strategies for altering their shape. J. Anim. Sci. 42, 1036-1051.

Goshu, A.T., Koya, P.R., 2013. Derivation of inflection points of nonlinear regression curves-implications to statistics. American Journal of Theoretical and Applied Statistics. 2, 268-272.

Hossein-Zadeh, N.G., 2015. Modelling the growth curve of Iranian Shall sheep using non-linear growth models. Small Rumin. Res. 130, 60-66.

Hötzel, M.J., Walkden-Brown, S.W., Fisher, J.S., Martin, G.B., 2003. Determinants of the annual pattern of reproduction in mature male Merino and Suffolk sheep: responses to a nutritional stimulus in the breeding and non-breeding seasons. Reprod. Fertil. & Dev. 15, 1-9.

Keskin, I., Dag, B., Sariyel, V., Gokmen, M., 2009. Estimation of growth curve parameters in Konya Merino sheep. S. Afr. J. Anim. Sci. 39, 163-168.

Lopez, B., Lupi, T.M., León, J.M., Lopez, F., Agudo, B., Delgado, J.V., 2018. Characterization of the commercial growth curves of Spanish Merino, Fleischschaf, and crossbred lambs in an associative economy context. Small Rumin. Res. 164, 8-14.

Malhado, C.H.M., Carneiro, P.L.S., Affonso, P.R.A.M., Souza, A.A.O., Sarmento, J.L.R., 2009. Growth curves in Dorper sheep crossed with the local Brazilian breeds, Morada Nova, Rabo Largo, and Santa Inês. Small Rumin. Res.84:16-21.

Moreira, R.P., Breno Pedrosa, V., Falcão, P.R., Sieklicki, M.D.F., Gomes Rocha, C., Cordeiro dos Santos, I., Maia Ferreira, E., de Souza Martins, A., 2016. Growth curves for Ile de France female sheep raised in feedlot. Semin-Ciênc. Agrár. 37, 303-309.

Nadarajah. K., Marlowe, T.J., Notter, D.R., 1984. Growth patterns of Angus, Charolais, Charolais× Angus and Holstein× Angus cows from birth to maturity. J. Anim. Sci. 59, 957-966.

National Research Council, 2017. Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids. National Academic Press, Washington DC., U.S.A. pp 256-261.

Nelder, J.A., 1961. The fitting of a generalization of the logistic curve. Biometrics. 17, 89-110.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci. 71, 3138-3150.

Schoeman, S.J., 2000. A comparative assessment of Dorper sheep in different production environments and systems. Small Rumin. Res. 36, 137-146.

Peters, F.W., Kotze, A., van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res. 90, 101-108

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. R. Bras. Zootec., 42, 675-690.

Von Bertalanffy, L., 1957. Quantitative laws in metabolism and growth. The quarterly review of biology. 32, 217-231.

Zishiri, O.T., Cloete, S.W.P., Olivier, J.J., Dzama, K., 2014. Genetic parameters for live weight traits in South African terminal sire sheep breeds. Small Rumin. Res. 116, 118-125.

# Chapter 4 - Predicting voluntary feed intake in different breeds of South African lambs from weaning to maturity


## Abstract

As lambs grow towards maturity, voluntary feed intake is adjusted in relation to the size of the sheep. This study investigated different approaches to describe and predict feed intake in different sheep breeds (Dohne Merino, Dormer, Dorper, Meatmaster, Merino, South African Mutton Merino (SAMM) and White Dorper breeds). Upon weaning at 90 days of age, four ram and four ewe lambs from the respective breeds were housed under feedlot conditions and reared on a high energy concentrate based diet until they reached maturity at ~12 months of age. During this period body weight and feed intake were recorded weekly. Daily dry matter intake (DMI) was modelled with body weight for the respective breeds using the quadratic function (DMI = $AW^2+BW+C$, where $W$ is body weight in kg). This model depicted the change in trends in feed intake in growing lambs, as feed intake increases before reaching a peak and then tending to decrease as lambs near maturity. However, this model accounted for less than 50% of the variation in the different productive groups. Linear regressions of percentage intake of body weight (PI) and cumulative feed intake with body weight were deemed to be more reliable in predicting voluntary feed intake levels (average $R^2$ values of 0.732 and 0.941, respectively). Differences for the various parameter estimates between rams and ewe lambs of the same breed were not found to be significant for the models of DMI and PI. The change in relative feed conversion ratio of the different breeds was modelled with an exponential relationship to model feeding efficiency of the growing lambs. Generally, lambs with larger frame sizes, such as the Dormer, Dorper and SAMM, presented higher feed intakes at a given body weight than smaller framed breeds. Later maturing SAMM lambs also proved to be more efficient in utilising feed for growth than the earlier maturing breeds.


**Keywords:** *Dry matter intake; Percentage intake; Feeding efficiency; Breeds*

## 4.1 Introduction

In livestock production, the level of intake, as well as the utilisation of the feed consumed, greatly influences the productive performance of an animal. Voluntary feed intake (VFI) in growing animals provides the organism with the specific nutrients for tissue growth and development according to its genetic potential, on the condition that nutrient requirements are met. In a sheep feedlotting operation, the goal is to add value to the conformation and size of the lamb, by subjecting it to an intensive feeding regime which will realise in accelerated growth to obtain a more desirable carcass. While growth is dependent on the amount of feed that the lamb consumes, intake in turn varies with the physical size of the animal along with the accompanying changes in maintenance requirements (Finlayson *et al* 1995). In a precision sheep feedlotting or finishing system it is important to be able to predict the change in VFI with the change in body weight of the growing lamb in order to firstly determine the amount of feed required to rear the lamb to a desired slaughter weight. It is also necessary in order to make adjustments to the nutrient composition in relation to the level of VFI to meet the requirements of growing lambs. Aside from the costs of purchasing weaner lambs, the nutritional costs to rear the lambs make up a major capital cost which directly influences the profitability of the system. It is therefore important to be able predict VFI to ensure sustainable management for profitable production.

Multiple models have previously been developed, mostly based on meta-analyses of studies to determine intake and nutritional requirements (Thompson & Parks, 1983; Cannas *et al*., 2004; Vieira *et al*., 2013). The inputs of the models though vary depending on the situation or production system that the model is specified for. The prediction and regulation of feed intake is complex as it is influenced by a multitude of factors, including animal factors, feed composition, bulkiness, passage rate as well as environmental factors such as photoperiod and ambient temperature (Ingvartsen, 1994; Allen, 1996; Pulina *et al*., 2013). Many of these factors are incorporated into the multiple regression models stated earlier depending on the design and purpose of the model. One of the main drivers included under the animal factors of an intake model is the influence of live weight on VFI. Emmans (1997) stated that the first step in modelling intake in growing animals is to first predict intake as a function of live weight. From there, additional factors can be included in the model to improve its fit, as well its application (Vieira *et al*., 2013). While the National Research Council (2017) does provide models to predict VFI for growing sheep, these models are based on meta-analyses that do not make allowance for differences in mature size, and so similar predictions are provided for breeds of different maturity types. It is often that the breed is not accounted for in such models (Ingvartsen, 1994) and so using body weight as a predictor of VFI is confounded by the degree of maturity of the animal. Previous models to predict intake did not include South African sheep breeds; it is thus postulated that due to the different breeds varying in mature body weight and maturation rate, that model parameters to predict the intake characteristics of the breeds will vary.

The aim of this study was to develop models that can be used to predict feed intake characteristics of feedlot reared lambs of different sheep breeds and maturity types, from weaning until they are assumed to have obtained mature body weight.

## 4.2 Materials and methods

### 4.2.1 Animal management

The protocol for this study was approved by the Western Cape Department of Agriculture's Departmental Ethical Committee for Research on Animals (DECRA R14/110). Lambs from seven different breeds were weaned at ~90 days of age (average weight of 30.4 kg ± 4.03) and housed under feedlot conditions on Elsenburg Research Farm. The seven breeds included in this study were selected as the most popular breeds in South African commercial lamb production systems and consisted of the Dohne Merino, Dormer, Dorper, Meatmaster, Merino, South African Mutton Merino (SAMM) and White Dorper breeds. Due to spatial restrictions in the housing facility, four ram lambs and four ewe lambs per breed were used to investigate intake trends in growing lambs from weaning until one year of age, when the lambs were assumed to have attained their mature body weight.

Upon weaning, the lambs were drenched and vaccinated with a broad-spectrum vaccine against Clostridia and Pasteurella bacterial infections and assigned to individual pens (1 m x 2 m) in the housing facility. The lambs were gradually adapted to the concentrate feedlot diet from an oat hay based roughage ration using a step-up program over a seven day period. After the adaptation period, lambs were supplied the feedlot diet (Table 4.1) *ad libitum,* and feed in the troughs was replenished twice a day. The feedlot diet used in this study resembled a high energy commercial lamb finisher concentrate, formulated according specifications for optimal growth rates (National Research Council, 2017). The feed used in this study was pelleted through a sieve 8.8 mm in diameter and the length of the pellets supplied was ~25 mm. During the study period, water was freely available to the lambs at all times.

**Table 4.1** Ingredient formulation and nutritional composition of feedlot diet fed to lambs during study period.

| Ingredient | Inclusion (g/kg As fed) |
|---|---|
| Maize | 500.0 |
| Lucerne hay | 361.0 |
| Cottonseed oilcake | 50.0 |
| Molasses powder | 25.0 |
| Ammonium chloride | 5.0 |
| Ammonium sulphate | 5.0 |
| Lime | 5.0 |
| Monocalcium phosphate | 5.0 |
| Common salt | 10.0 |
| Urea | 5.0 |
| Sodium Bicarbonate | 10.0 |
| Slaked lime | 5.0 |
| Sulphur | 2.0 |
| Vitamin and mineral premix | 1.5 |
| Commercial growth promoters and coccidiostat premix | 1.2 |

| Nutrient | Composition |
|---|---|
| Dry matter, g/kg | 885.0 |
| Total digestible nutrients (TDN, g/kg)[1] | 661.5 |
| Metabolisable energy, MJ/kg | 9.92 |
| Nitrogen free extract[2], g/kg | 495.9 |
| Crude protein, g/kg | 160.8 |
| Rumen undegradable protein (RUP)[3], g/kg | 43.0 |
| Crude fibre, g/kg | 109.1 |
| Neutral detergent fibre, g/kg | 205.1 |
| Acid detergent fibre, g/kg | 143.3 |
| Ash, g/kg | 98.0 |
| Fat, g/kg | 21.2 |
| Calcium, g/kg | 13.9 |
| Phosphorous, g/kg | 4.3 |

[1]Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fibre) + (0.9 x nitrogen free extract) + (2.025 x fat).

[2]Calculated Nitrogen free extract =100–(moisture +ash + protein + crude fibre+ fat).

[3]RUP calculated from protein degradability values for maize (63.0%), lucerne meal (68.9%) and cottonseed oilcake (54.5%), at an outflow rate of 0.05/hr (Erasmus *et al*.,1988; Erasmus *et al*., 1990a; Erasmus *et al*., 1990b).

The lambs were weighed at the same time each week, in the morning before feeding. At the same time, the weekly feed refusals were weighed in order to determine feed intake. The refusals were subtracted from the amount of feed supplied and divided by the number of days in order to give daily feed intake on a dry matter basis (DMI). Feed samples as well as refusal samples were oven dried at 100°C for 24 hours in order to determine dry matter content. The DMI was also expressed as a percentage of the body weight of the lambs of the previous week in order to give the percentage intake (PI). The cumulative feed intake (CFI) was also calculated over the study period. The relative feed conversion ratio (FCR) was also calculated by dividing the DMI by the respective average daily gain (ADG) at that specific body weight. The ADG was determined by differentiating the Gompertz growth curves [$W = A \times \exp(-\exp(-B(Age - C)))$] fitted to the cumulative body weights of the individual lambs to determine the slope (growth rate) at weight *W*.

### 4.2.2 Statistical analysis

The growth and feed intake data were statistically analysed using SAS enterprise guide (SAS, 2006). Outliers deviating (more than three standard deviations) from mean trends of the dataset were removed from the dataset and trends were identified. A quadratic polynomial function was fitted in order to describe the relationship between DMI and body weight of the lambs using the PROC NLIN function of SAS. Iteration of the parameter estimates was performed using the Guass-Newton method. Similarly, the exponential function was fitted to describe the relationship between FCR and body weight using the same procedure. Linear regressions were performed to describe the respective relationships of cumulative feed intake and PI with body weight using PROC REG of SAS. The parameter values of the respective regression models were compared between the main effects of breed and sex, as well as the interaction between these effects, using the general linear model procedure of SAS. The parameter values were then expressed as least square means with accompanying standard errors. Differences between the main effects were considered to be significant at the $P \leq 0.05$ level, while tendencies were declared at the $P \leq 0.10$ significance level.

## 4.3 Results

In this study, the DMI of each of the lamb production groups increased with body weight of the lambs in a curvilinear fashion. Therefore, a quadratic polynomial function was deemed to be most appropriate in describing this trend and was fitted to the individual curves presented by the animals. The model parameters, or coefficients, were compared to demonstrate any differences between breed and sex (Table 4.2). No differences were observed between ewes and rams for any of the model parameters ($P > 0.05$). Though a tendency may exist for ewes to present lower *A* parameter estimates than rams (-0.696 and -0.531, respectively; *P* <0.10). Dohne Merino and Meatmaster lambs displayed the highest estimates for the *A* (-0.371 and -0.409, respectively) and *C* (546.11 and 316.23, respectively) parameters, while the lowest estimates were obtained by the White Dorper lambs (-0.964 and -1374.66 for the *A* and *C* parameters respectively). Conversely, the opposite trend was observed with the *B* parameter. The lowest *B* parameter estimates were obtained by the Dohne Merino (42.163) and Meatmaster (48.938) breeds, while the White Dorper group obtained the highest estimate of 112.012 (*P* ≤0.05). The parameter values of the Dormer, Dorper, Merino and SAMM breeds did not differ from that of any of the other breeds for either of the *A*, *B* or *C* parameter estimates of the quadratic function describing the change in DMI with body weight. The estimated quadratic curves for the various breeds were also plotted (Figure 4.1).

**Table 4.2** Comparison of quadratic regression model parameters to predict daily feed intake from body weight of rams and ewes of different breeds, between weaning and maturity.

| Main effect | | Parameter | | |
|---|---|---|---|---|
| | | ***A*** | ***B*** | ***C*** |
| Sex | Ram | -0.531 ± 0.0633 | 71.211 ± 7.022 | -365.84 ± 202.97 |
| | Ewe | -0.696 ± 0.0610 | 78.279 ± 6.762 | -447.32 ± 187.13 |
| | *P-value* | *0.072* | *0.613* | *0.769* |
| | | | | |
| Breed | Dohne Merino | $-0.371^{a} \pm 0.1159$ | $42.163^{b} \pm 1.284$ | $546.11^{a} \pm 352.35$ |
| | Dormer | $-0.818^{ab} \pm 0.1159$ | $100.212^{ab} \pm 1.284$ | $-865.90^{ab} \pm 352.35$ |
| | Dorper | $-0.711^{ab} \pm 0.1197$ | $90.740^{ab} \pm 1.326$ | $-888.22^{ab} \pm 363.91$ |
| | Meatmaster | $-0.409^{a} \pm 0.1159$ | $48.938^{b} \pm 1.284$ | $316.23^{a} \pm 352.35$ |
| | Merino | $-0.506^{ab} \pm 0.1159$ | $59.287^{ab} \pm 1.284$ | $-177.04^{ab} \pm 352.35$ |
| | SA Mutton Merino | $-0.515^{ab} \pm 0.1159$ | $69.863^{ab} \pm 1.284$ | $-402.55^{ab} \pm 352.35$ |
| | White Dorper | $-0.964^{b} \pm 0.1159$ | $112.012^{a} \pm 1.284$ | $-1374.66^{b} \pm 352.35$ |
| | *P-value* | *0.005* | *0.001* | *0.005* |

$^{a\text{-}b}$ Means with different superscripts in columns differ (*P* ≤0.05).

DMI = $AW^2 + BW + C$, where DMI is represents daily feed intake (g) and *W* is the body weight of the lambs in kg.

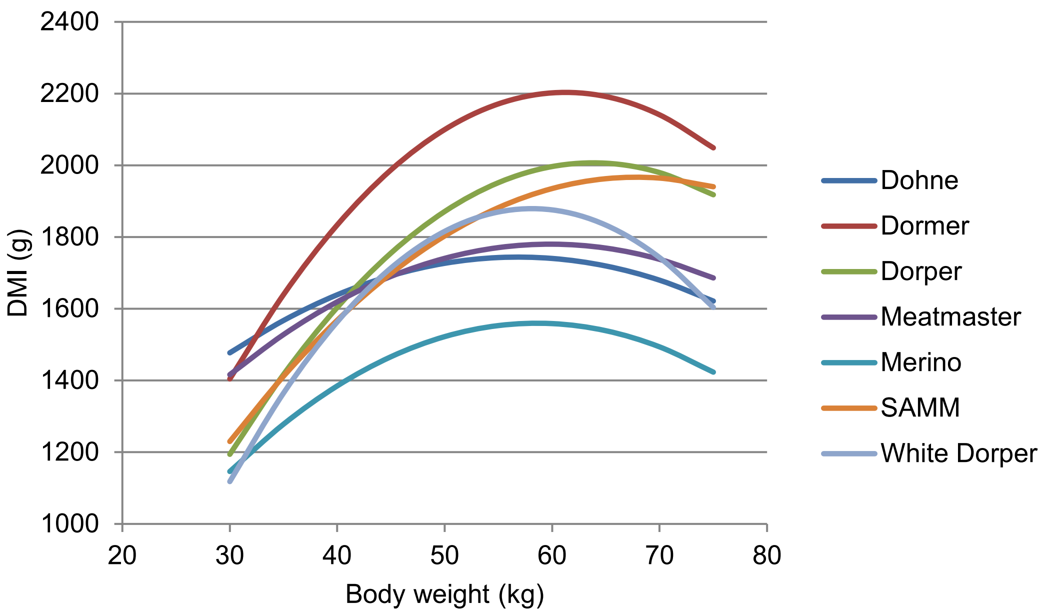


**Figure 4.1** Graphical representation of quadratic functions describing the trends in daily dry matter intake (DMI) with body weights of growing lambs from the respective breeds.

Though no significant interactions were observed between breed and sex for the parameters to describe the quadratic relationship between DMI and body weight, separate regression equations for the specific respective production groups are presented (Table 4.3). Although these models describe the general pattern that DMI follows with an increase in body weight, the quadratic models accounted for only a small portion of the variation of the data. Regressing the predicted values against observed measurements showed that the highest R-square value was observed for the model describing DMI of Dormer ewes ($R^2$ =0.464), while the lowest was obtained by Merino ewes and rams as well as White Dorper rams (0.057, 0.044 and 0.47, respectively). With less than 50% of the variation being described by these models, it can be said that accurate DMIs cannot be predicted reliably from body weight of growing lambs using a quadratic function.

**Table 4.3.** Quadratic regression models to describe daily feed intake (g) from body weight (kg) the various lamb production groups.

| Breed | Sex | Equation | $R^2$ |
|---|---|---|---|
| Dohne Merino | Ewe | $-0.358W^2 + 35.275W + 713.40$ | 0.253 |
| | Ram | $-0.385W^2 + 49.050W + 378.83$ | 0.326 |
| Dormer | Ewe | $-0.907W^2 + 107.600W - 1039.43$ | 0.464 |
| | Ram | $-0.730W^2 + 92.825W - 692.38$ | 0.255 |
| Dorper | Ewe | $-1.056W^2 + 118.180W - 1407.04$ | 0.207 |
| | Ram | $-0.365W^2 + 63.30W - 369.40$ | 0.316 |
| Meatmaster | Ewe | $-0.463W^2 + 52.175W + 402.50$ | 0.172 |
| | Ram | $-0.355W^2 + 45.700W + 229.95$ | 0.192 |
| Merino | Ewe | $-0.555W^2 + 57.350W - 60.53$ | 0.044 |
| | Ram | $-0.458W^2 + 61.225W - 293.55$ | 0.057 |
| SA Mutton Merino | Ewe | $-0.540W^2 + 66.000W - 198.55$ | 0.110 |
| | Ram | $-0.490W^2 + 73.725W - 606.55$ | 0.126 |
| White Dorper | Ewe | $-0.933W^2 + 111.375W - 1369.03$ | 0.204 |
| | Ram | $-0.995W^2 + 112.650W - 1380.30$ | 0.047 |

As accurate models to predict DMI in growing lambs could not be developed, daily VFI was also expressed as a percentage of body weight and then regressed against the body weight of the growing lambs (Tables 4.4 and 4.5). The PI was shown to decrease linearly with body weight. The parameter coefficients of the linear regressions were compared to determine any difference caused by the main effects of sex and breed (Table 4.4). No interactions were observed between the main effects for either the *A* or *B* parameters of the linear regression of PI with body weight. Neither the sex, nor the breed, influenced the *A* parameter ($P$ >0.05), giving an average value of 6.082 for the intercept of PI when body weight is equal to zero. Though, a tendency was observed for the intercept of Dormer lambs to be higher than that of Merino lambs (6.835 *vs.* 5.434, respectively; $P$ <0.10). The slope *B* was found to be negative for all of the production groups due to the decreasing nature of trends shown by PI with body weight. The slope of the regression was 19% lower for rams than that of ewes ($P$ ≤0.05). The slope for the change of PI with body weight, however, did not vary between the different breeds ($P$ >0.05), giving an average value of -0.0499 for the slope of the regression.

**Table 4.4** Comparison of linear regression parameters to describe feed intake as a percentage of body weight (PI) from body weight of lambs of different breeds, between weaning and maturity.

| Main effect | | Parameter | |
|---|---|---|---|
| | | ***A*** | ***B*** |
| Sex | Ram | 6.045 ± 0.159 | -0.0456 ± 0.0024 |
| | Ewe | 6.118 ± 0.153 | -0.0543 ± 0.0023 |
| | *P-value* | *0.745* | *0.013* |
| Breed | Dohne Merino | 6.282 ± 0.290 | -0.0554 ± 0.0044 |
| | Dormer | 6.835 ± 0.290 | -0.0552 ± 0.0044 |
| | Dorper | 6.149 ± 0.300 | -0.0484 ± 0.0045 |
| | Meatmaster | 6.047 ± 0.290 | -0.0493 ± 0.0044 |
| | Merino | 5.434 ± 0.290 | -0.0474 ± 0.0044 |
| | SA Mutton Merino | 5.742 ± 0.290 | -0.0426 ± 0.0044 |
| | White Dorper | 6.083 ± 0.290 | -0.0513 ± 0.0044 |
| | *P-value* | *0.054* | *0.406* |

[a-b] Means with different superscripts in columns differ ($P \leq 0.05$).

PI = $A + BW$, where PI represents percentage intake (%) and $W$ denotes body weight (kg)

While no interactions were observed for the parameter estimates of the linear regression of PI with body weight, separate equations are presented for the various production groups to predict PI for the specific group (Table 4.5). R-square coefficients of determination showed that more than 50% of the variation of the data in the respective production groups was accounted for by the linear models. The R-square values were generally high, with the exceptions of Dorper and Merino ram groups ($R^2$ <0.600), while the highest value was realised for the model describing PI in Dohne Merino rams ($R^2$ =0.878).

**Table 4.5** Linear regression models to predict percentage feed intake of body weight (%) from body weight (kg) for the various lamb production groups.

| Breed | Sex | Equation | $R^2$ |
|---|---|---|---|
| Dohne Merino | Ewe | 6.283 – 0.0607*W* | 0.854 |
| | Ram | 6.281 – 0.0501*W* | 0.878 |
| Dormer | Ewe | 6.919 – 0.0588*W* | 0.855 |
| | Ram | 6.751 – 0.0516*W* | 0.721 |
| Dorper | Ewe | 6.487 – 0.0571*W* | 0.698 |
| | Ram | 5.812 – 0.0396*W* | 0.532 |
| Meatmaster | Ewe | 6.005 – 0.0518*W* | 0.748 |
| | Ram | 6.089 – 0.0467*W* | 0.786 |
| Merino | Ewe | 5.519 – 0.0540*W* | 0.719 |
| | Ram | 5.349 – 0.0409*W* | 0.561 |
| SA Mutton Merino | Ewe | 5.883 – 0.0486*W* | 0.753 |
| | Ram | 5.600 – 0.0366*W* | 0.754 |
| White Dorper | Ewe | 5.728 – 0.0488*W* | 0.669 |
| | Ram | 6.437 – 0.0539*W* | 0.714 |

Cumulative feed intake was calculated over the study period, and was regressed with body weight of the growing lambs. The cumulative feed intake was found to increase linearly with respect to the increase in body weight of the growing lambs. The comparisons of regression model parameters for CFI are presented in an interaction table (Table 4.6), due to the significant interactions observed between breed and sex for the slope parameter *B*. In contrast no significant interactions were observed between breed and sex for the intercept of the curve *A*, showing no differences between the various production groups ($P$ >0.05). While no interactions were observed, the effect of breed did influence the magnitude of the *A* parameter ($P$ =0.031), with the Dormer and Merino breeds presenting higher values (-221.052 and -227.71, respectively) than the Dohne Merino and Dorper breeds (-266.59 and -270.07, respectively). That of the SAMM (-249.76) and Meatmaster (-252.33) breeds did not differ from any of the other breeds ($P$ >0.05), while the *A* parameter of Dormer lambs was higher than that of White Dorper lambs (-260.81; $P$ ≤0.05), which in turn did not differ from that of the Dohne Merino and Dorper breeds ($P$ >0.05). For the slope of the regression (*B* parameter), a lower slope was obtained by SAMM rams (5.808) compared to Dohne Merino, Meatmaster and White Dorper ewes and rams, as well as Dormer, Dorper, Merino and SAMM ewes (~7.293). On the other hand, the *B* parameters of Dormer, Dorper and Merino rams did not differ from that of any of the other production groups ($P$ >0.05) with an average value of 6.779. The coefficients of the determination for the models of the respective production groups were quite high, indicating that the models to predict CFI account for more than 87% of the variation of the data in the respective groups.

**Table 4.6** Linear regression models to predict cumulative feed intake from the body weight of the various lamb production groups.

| Breed | Sex | Parameter *A* | Parameter *B* | $R^2$ |
|---|---|---|---|---|
| Dohne Merino | Ewe | -258.84 ± 16.41 | $7.571^{a}$ ± 0.237 | 0.963 |
| | Ram | -274.34 ± 16.41 | $7.339^{a}$ ± 0.237 | 0.940 |
| Dormer | Ewe | -236.28 ± 16.41 | $7.087^{a}$ ± 0.237 | 0.962 |
| | Ram | -205.82 ± 16.41 | $6.626^{ab}$ ± 0.237 | 0.941 |
| Dorper | Ewe | -245.82 ± 14.68 | $7.065^{a}$ ± 0.212 | 0.941 |
| | Ram | -294.34 ± 18.95 | $7.062^{ab}$ ± 0.273 | 0.910 |
| Meatmaster | Ewe | -245.70 ± 16.41 | $7.525^{a}$ ± 0.237 | 0.965 |
| | Ram | -258.95 ± 16.41 | $7.185^{a}$ ± 0.237 | 0.963 |
| Merino | Ewe | -223.97 ± 16.41 | $7.426^{a}$ ± 0.237 | 0.936 |
| | Ram | -231.45 ± 16.41 | $6.650^{ab}$ ± 0.237 | 0.960 |
| SA Mutton Merino | Ewe | -264.14 ± 16.41 | $7.299^{a}$ ± 0.237 | 0.946 |
| | Ram | -235.39 ± 16.41 | $5.808^{b}$ ± 0.237 | 0.957 |
| White Dorper | Ewe | -251.93 ± 16.41 | $7.171^{a}$ ± 0.237 | 0.919 |
| | Ram | -269.68 ± 16.41 | $7.264^{a}$ ± 0.237 | 0.873 |
| *P-value* | | *0.238* | *0.033* | |

[a-b] Means with different superscripts in columns differ ($P \leq 0.05$).

CFI= $A + BW$, where CFI represents cumulative feed intake (kg), and $W$ denotes body weight (kg).

In intensive feeding operations it is also important to predict the efficiency at which feed is utilised for growth. An exponential function was used to model the change in FCR with body weight of the lambs, with varying accuracies (Table 4.7). The curves for the increase in FCR are also depicted in Figure 4.2 for ram and ewe lambs. The highest R-square value was realised by the model to predict FCR of Merino ram lambs (0.756); yet, the Dormer groups, Dorper ewes and Merino ewes presented R-squares with less than 50% of the variation being accounted for by the respective models. An interaction ($P \leq 0.05$) was observed between breed and sex for the *A* parameter of the model, with the parameter estimate of Dohne rams (2.883) being significantly greater than that of SAMM ewes (0.892) ($P \leq 0.05$), while that of the other production groups did not differ from each other ($P > 0.05$). While no significant interactions were observed between breed and sex for the *B* parameter, ewes (0.0304) were found to have higher *B* values than their male counterparts (0.0233) ($P = 0.045$). The effect of breed on the other hand, did not significantly influence the magnitude of the *B* parameter estimates of the exponential models to predict FCR from body weight of the lambs.

**Table 4.7** Comparison of exponential regression model parameters to feed conversion ratio (FCR in kg feed/ kg weight gain) from body weight of lambs of different breeds, between weaning and maturity.

| **Breed** | **Sex** | **Parameter** | | **$R^2$** |
|---|---|---|---|---|
| | | ***A*** | ***B*** | |
| Dohne Merino | Ewe | $1.242^{ab} \pm 0.374$ | $0.0328 \pm 0.0064$ | 0.663 |
| | Ram | $2.883^{a} \pm 0.374$ | $0.0133 \pm 0.0064$ | 0.667 |
| Dormer | Ewe | $1.794^{ab} \pm 0.374$ | $0.0309 \pm 0.0064$ | 0.469 |
| | Ram | $1.191^{ab} \pm 0.374$ | $0.0379 \pm 0.0064$ | 0.433 |
| Dorper | Ewe | $1.475^{ab} \pm 0.335$ | $0.0322 \pm 0.0058$ | 0.479 |
| | Ram | $0.935^{ab} \pm 0.432$ | $0.0286 \pm 0.0074$ | 0.697 |
| Meatmaster | Ewe | $1.819^{ab} \pm 0.374$ | $0.0245 \pm 0.0064$ | 0.646 |
| | Ram | $2.658^{ab} \pm 0.374$ | $0.0154 \pm 0.0064$ | 0.686 |
| Merino | Ewe | $1.864^{ab} \pm 0.374$ | $0.0299 \pm 0.0064$ | 0.387 |
| | Ram | $1.350^{ab} \pm 0.374$ | $0.0277 \pm 0.0064$ | 0.756 |
| SA Mutton Merino | Ewe | $0.892^{b} \pm 0.374$ | $0.0358 \pm 0.0064$ | 0.632 |
| | Ram | $2.010^{ab} \pm 0.374$ | $0.0156 \pm 0.0064$ | 0.642 |
| White Dorper | Ewe | $1.592^{ab} \pm 0.374$ | $0.0267 \pm 0.0064$ | 0.688 |
| | Ram | $1.700^{ab} \pm 0.374$ | $0.0245 \pm 0.0064$ | 0.537 |
| *P-value* | | *0.018* | *0.335* | |

$^{a-b}$ Means with different superscripts in columns differ ($P \leq 0.05$).

FCR= $A \cdot \exp(BW)$, where $W$ denotes body weight (kg).

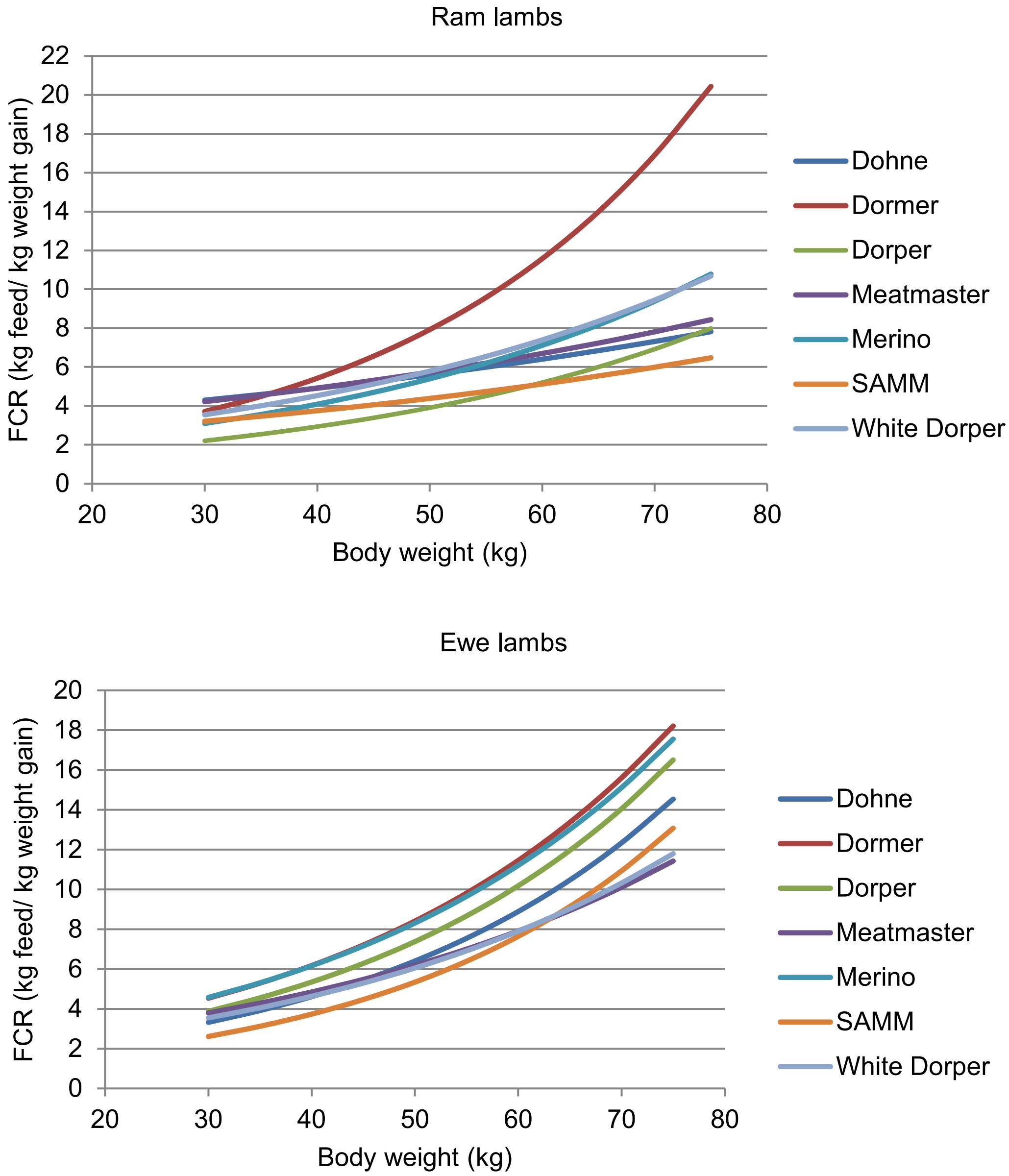


**Figure 4.2** Graphical representation of exponential increasing trends of feed conversion ratio (FCR) with body weight of growing ram (top) and ewe (bottom) lambs from the respective breeds.

## 4.4 Discussion

Voluntary feed intake is the primary driver for an animal to realise its potential for growth and production. Therefore, it is the most important management factor in livestock production, particularly in intensive systems. In an intensive feedlotting system, the goal is to maximise feed intake and optimise feed utilisation so as to accomplish optimal growth of the finishing stock so as to ensure efficiency and sustainability of the operation. In order to apply good management principles, a clear understanding of the trends followed, and the factors that influence feed intake, are key. It has been shown that sheep and goats consume feed to firstly satisfy their nutritional (energy and protein) requirements (Faverdin, 1999; Illius *et al.*, 2000;

Brand *et al*., 2017). Though on low energy, high roughage based diets the physical form and bulk density of the feed becomes a strong limiting factor which influences the passage rate as well as the amount of feed consumed (Allen, 1996). Methods of possibly improving feed intake include manipulating the nutritional composition and physical form of the feed (Ingvartsen, 1994), as well as increasing the feeding frequency during the day. Increasing the number of feeding times with small quantities of feed, opposed to fewer feeding periods with larger feed quantities, has the possibility of enhancing intake, and thus growth (Gibson, 1981). Though, it has been suggested that while this method enhances intake and growth, it may reduce feeding efficiency by increasing passage rate through the gastrointestinal tract (Muir *et al*., 2018). In addition to these factors, the animal factor cannot be ignored; sheep exhibit selective feed intake based on palatability and particle size of the feed that cause varying passage rates and rumination times (Pulina *et al*., 2013). Though, the main factors driving the potential level of feed intake are related to body size of the animal, as well as its physiological status, which determines its maintenance requirements (Tolkamp *et al.,* 2006; Zereu, 2016). Cannas *et al*., (2004) accordingly took body weight as well as production level of sheep into account in models to predict the level of intake.

The size of the animal determines the capacity of feed that can be consumed as well as the maintenance requirements for body tissues. As lambs grow, increasing amounts of energy are required for protein and fat tissue growth before maintenance requirements exceed that needed for growth (Johnson *et al.,* 2012). Daily feed intake of the lambs in this study was seen to increase before plateauing in a curvilinear fashion relative to body weight for all breed groups during the study (Tables 4.2 and 4.3). A quadratic function was found to best represent this relationship between DMI and body weight which was characterised by an initial increase in DMI until a maximum was reached, after which there was an apparent decline in DMI as body weights increased. The intake of Suffolk sheep was modelled with the same function (Lewis & Emmans 2010); in addition, Ministry of Agriculture Fisheries and Food (1975) also proposed a simple quadratic function to predict DMI from body weight only for growing cattle. Cannas *et al*. (2004) though, used a linear representation incorporating metabolic body weight as well as growth rate to predict the intake of growing lambs. Using factor analysis in the current study, the inclusion of growth rate with body weight did not provide any significant improvement to DMI prediction models and was thus not incorporated. It is suggested that this approach may be bordering on a mechanistic model describing the growth of tissues while the aim of this study is to present a simple empirical model to predict feed intake from body weight.

With the quadratic relationship between DMI and body weight, the initial increase in feed intake can be ascribed to the lambs increasing their level of feed intake in order to meet their metabolic requirements for growth, as their bodies grow in size and mass. It would be expected that a maximum DMI would be reached as the lambs near maturity, which would then plateau off. However, in this study DMI decreased after attaining a maximum which may be as a result of increased fat deposition in the growing lambs. Johnson *et al*. (2012) stated that there is a high variation in intake as a ruminant nears maturity, which may be accompanied by fat loss. It is hypothesised that increased fat deposition in the abdominal cavity of lambs may cause physical restrictions; displacing rumen contents and so slowing down passage rate and intake (Forbes, 2007). Following this study, the mature sheep that were reared in the trial were slaughtered at a registered commercial abattoir and the carcass and non-carcass components were collected and weighed. It was observed that abdominal fat contributed 6% of the body weight in wool sheep and 7.3% in the hair type sheep; while the yield of the gastrointestinal tract (after 24 hours fasting) varied from 10.8% in Merino, Dormer and White Dorper sheep to 12.2% in Dohne Merino, Dorper, Meatmaster and SAMM sheep. This shows that abdominal fat made up a considerable portion of weight attributed to the abdomen along with the gastrointestinal tract and so supporting the theory that increased abdominal fat deposition may influence feed intake by imposing physical restrictions on the gastrointestinal tract. Another possible effect of increased fat deposition is the amplified plasma leptin levels from adipose tissue suppressing hunger feedback systems. The increase in plasma leptin concentrations have been associated with a suppression of appetite and reducing feed intake (Marie *et al*., 2001), and it is suggested that the provision of high energy diet supplied along with reduced movement in the feedlot lead to high levels of fat deposition in lambs as they became heavier, which may result in higher levels of leptin being released from adipose tissue.

While describing the trends in DMI followed by growing lambs; the quadratic model for predicting the absolute DMI from body weight of lambs, however, only accounted for a small portion of the variation of the data of the various production groups (<46%). It is advised that more factors be incorporated into the model in order to improve its accuracy. Tolkamp *et al*., (2006) also described the curvilinear relationship between intake and body weight, and stated that body weight alone is insufficient to account for the variation in feed intake. Relevant feed factors (that influence intake and digestibility), which are easy to quantify and detect, can be incorporated as variables into the model along with environmental factors (which influence the metabolic rate of the lambs) in order to improve the accuracy of prediction (Blaxter *et al*., 1966; Pulina *et al*., 2013). While the additions of these mechanisms improve the accuracy of prediction as well as understanding of the model, it is still heavily dependent on the empirical relationship of the change in intake with body weight (Illius *et al*., 2000).

In order to simplify prediction of VFI in a lamb feedlot system, where grain concentrates are typically served to the lambs, alternative models relating intake to body weight were explored. Expressing intake as a percentage of body weight and regressing against body weights of the lambs improved the accuracy of prediction, with 53-87% of the variation being accounted for (Table 4.5). Percentage intake does decrease in relation to body weight and is generally accepted to decrease from 4-3% as lambs grow from 30 kg to 80 kg body weight (provided that growth rate remains constant) (National Research Council, 2017). The linear decline in percentage intake occurred at a similar rate for all of the breeds in this study with intakes predicted to range from 4-5% in lambs weighing 30 kg and dropping to 2-3% in lambs weighing about 70 kg. Cumulative feed intake was also expressed linearly in relation to the increase in body weights of the lambs over the study period with high accuracies ($R^2$ >0.87). The slope of the regression also represents the average FCR of the lambs over the entire rearing period. As lambs are often introduced to the rearing conditions at different ages and body weights and reared for different periods, it is expected that the points at which the curve intercept the axes will vary between production systems. The factors by which the cumulative feed intake increases with body weights are then expected to remain constant for the respective production groups. The model for cumulative feed intake thus must be adjusted for the starting weight of the production system, though the relative proportion by which it increases with body weight will remain constant. This can be achieved easily without correction between breeds, due to the lack of differences observed between the intercepts of the production groups. While these models to predict percentage intake of body weight and cumulative intake give a better prediction of feed intake than the proposed quadratic model, the prediction results must still be converted back to DMI. This may be complicated when using cumulative feed intake, as growth rate needs to be considered to perform this calculation. Again, other factors affecting intake and feed digestibility must also be taken into account when applying these models to systems feeding different levels of concentrates.

One cannot discuss the trends in VFI without making mention of how efficiency of feeding is influenced. Looking at the absolute amount of feed required to gain a unit of body weight (FCR) at regular intervals presents a large amount of variation within an individual with no clear specific pattern. Therefore, FCR must be considered over specific rearing periods (weight intervals) or it must be determined in relation to the sigmoidal growth curve rather than the absolute growth rate. In this study, the growth rates were determined as the slopes of the Gompertz growth curves of the individual lambs (Emmans, 1989) and FCR was expressed as feed intake as a proportion of this growth rate at that specific body weight. An exponential relationship can then be observed between FCR and body weight of the growing lambs (Table 4.7). These models depict an increase in FCR, indicating body weights at which it becomes unfeasible to rear lambs in a finishing system. These points of inflection are often expected to relate to the level of fat deposition in lambs, as fat tissue growth increases as the lamb grows and so increasing the amount of energy per unit body weight gain (Johnson *et al*., 2012).

With an understanding of the applications and trends exhibited by the models used in this study, the differences shown by the various production groups can now be discussed. Most models do not take breed into consideration when predicting feed intake (Ingvartsen, 1994), which is important as breeds differ in their body size and tissue composition and level of maturity at a specific body weight. The predictions of the polynomial models of the different breeds (Table 4.2) were compared with estimates described by the National Research Council (2017) for late maturing and early maturing sheep at body weights ranging between 20-60 kg. The estimates selected, were based on diets containing the same energy density as that in the current study (9.92 MJ ME/kg feed). Comparisons showed that on average polynomial predictions of DMI for Dohne Merino, Dormer, Meatmaster and SAMM breeds were 32% greater than that presented for late maturing sheep, while predictions for Merino, Dorper and White Dorper breeds were 19% greater than these values. With regard to National Research Council (2017) intake estimates for early maturing sheep, Dohne Merino, Dormer and Meatmaster intakes were on average 14% greater, while that of Dorper and SAMM were only 5% greater and that of Merino and White Dorper were 7% lower than the estimates. It is clear that the intakes predicted in this study are greater than the reported estimates for late maturing lambs, smaller differences were noted when compared with estimates for early maturing lambs. Meatmaster and Dorper breeds are generally regarded as early maturing breeds, in terms of physiological maturity, while Dohne Merino, Dormer, Merino and SAMM are later maturing, which does not follow the trends for differences between intake estimates. Use of the estimates provided by the National Research Council (2017) may therefore underestimate feed intake at a given body weight for the breeds included in this study.

Differentiating the quadratic functions of the different breeds revealed the peak feed intakes predicted by the curves. Dormers had the highest estimated peak intakes of 2203 g/day at a weight of 61.3 kg, followed by Dorper (2007 g/day, 63.8 kg), SAMM (1958 g/day, 72.0 kg), White Dorper (1879 g/day, 58.1 kg), Meatmaster (1780 g/day, 59.8 kg), Dohne Merino (1744 g/day, 56.8 kg) and Merino displaying the lowest peak (1560 g/day, 58.6 kg) (Figure 4.1). On average the peak intakes of ewes were 13.4% lower than that of rams which were attained at 16.2% lower body weights. These trends in DMI resemble the intake trends calculated by Meissner *et al.* (1983) for South African wool, dual-purpose and Dorper lambs. Although, the peak intakes of rams in the current study were estimated to be 4.5% higher for wool sheep (Merino), 28.1% higher for dual-purpose sheep (SAMM) and 10.6% higher for the Dorpers compared to that calculated by Meissner *et al.* (1983). It is expected that breeds with larger body conformations (such as the Dormer, SAMM and Dorper) would consume greater quantities of feed due to their greater metabolic demand than the smaller framed and wool breeds. It is reassuring that the trends in the current study mimicked that of Meissner *et al.* (1983), where intakes were calculated using the energy requirements of the various breeds, though these values are lower than that demonstrated in the present study.

By describing VFI in terms of percentage intake, more accurate predictions can be made than using the quadratic polynomial function for DMI. Lewis & Emmans (2010) described the use of a standardised intake, to express intake as a proportion of body weight relative to the degree of maturity. When VFI was presented as a percentage of body weight, the linear decline in percentage intake with increase body weight occurred at a similar rate for all breeds (0.05% per kg body weight). Though intercept values of the regressions approached significance, indicating that the Dormer lambs have the highest percentage intakes while Merino lambs tend to have the lowest percentage intakes. This can again be ascribed to the larger body size and greater proportion of metabolic tissue of Dormer sheep that have been bred for enhanced meat production traits compared to the smaller frame size of the wool producing Merino sheep (Cloete *et al*., 2003).

From the cumulative intake curves, the slopes indicate that over the study period SAMM rams were more efficient in converting feed into body growth by obtaining the lowest regression slope. This is confirmed in Figure 4.2, which illustrates that at a given body weight SAMM lambs generally present the lowest FCR values. The FCR curves of ewe lambs (Figure 4.2) generally increase at a greater rate than that of ram lambs. This is due to ewes starting to deposit fat at lower live weights than rams, thus increasing their metabolic requirements and reducing the efficiency of feed utilisation for growth (Owens *et al*., 1993). The Dormer breed showed higher rates of FCR increase with body weight, again owing to higher levels of fat deposition. Alternatively, the SAMM breed is later maturing and so has lower levels of fat deposition and therefore exhibits a better feed efficiency (Cloete *et al*., 2004). It would be expected that the Dorper, an early maturing breed, would show a relatively sharp increase in FCR with body weight, however, the curve for Dorper rams followed a similar trend to SAMM rams, indicating a high feed efficiency. In Figure 4.1 it can be seen that the trends of the DMI curves for Dorper and SAMM breeds closely resemble each other. As Dorper rams maintained high growth rates during the study, and similar intakes to that of SAMM sheep, they showed similar trends in feed efficiency, even while the Dorper is known to deposit fat at an earlier age. The FCR of Merino ewes mimics the same trend as that of Dormer ewes (Figure 4.2), which is possibly due to the lower growth rates exhibited by Merino ewes relative to other breeds (Van der Merwe *et al*., 2019).

Due to the differences in the level of feed intake, as well as feed efficiency, of different breeds and sexes at the same body weights; separate models are required to predict feed intake trends of different production groups (Tables 4.3, 4.5, 4.6 and 4.7). These differences between breeds can mainly be attributed to differences in frame size, maturity type, growth rate and production potential for meat or wool. The same model can only be used for breeds with different mature weights if DMI is similar at the same body weight (Lewis & Emmans, 2010). In Figure 4.1 it can be seen that the trends of Dorper, SAMM and White Dorper (up to 55 kg) are fairly similar, while the intakes of Meatmaster and Dohne lambs are closely related but differ from the former group. This study defines the changes in feed intake characteristics observed in lambs reared on a pelleted concentrate diet, as they increase in body weight from weaning to maturity. The models in this study are empirical in nature and the inclusion of feed and environmental factors may be necessary to improve the accuracy of prediction. These models align with trends described in literature and predict levels that can be expected for the different breeds, reared under optimal sheep feedlotting conditions, as in this study.

## 4.5 Conclusion

Modelling DMI using the quadratic function in this study gave an indication of the dynamics of VFI and how trends change with the growth of lambs of various breeds. However this model was not deemed to be accurate in predicting the actual DMI levels. By modelling feed intake in terms of a percentage of body weight, more reliable models were obtained to predict DMI values. The use of cumulative feed intake was found to account for the greatest proportion of the data, though it is more indicative of the feed efficiency over the entire rearing period and may change depending on the rearing conditions. The models of FCR show that feed efficiency is subject to change with the weight of the lambs, which must be considered when adopting cumulative feed intake for a specific rearing period. While it is relatively simple to determine DMI from PI at a given body weight, in order to determine DMI from CFI requires knowledge of the growth rates of lambs at a given body weight.

Generally higher levels of VFI are observed in larger framed sheep breeds in order to supply sufficient nutrients for growing tissues, than for smaller framed animals with slower growth rates. Overall, SAMM lambs and Dorper rams presented the most desirable feeding efficiencies at a given body weight, while early maturing breeds with higher degrees of fatness presented the highest FCRs at heavier body weights.

## References

Allen, M.S., 1996. Physical constraints on voluntary intake of forages by ruminants. J. Anim. Sci., 74, 3063–3075.

Blaxter, K.L., Clapperton, J.L., Wainman, F.W., 1966. The extent of differences between six British breeds of sheep in their metabolism, feed intake and utilization, and resistance to climatic stress. British journal of Nutrition, 20, 283–294.

Brand, T.S., Van der Merwe, D.A., Swart, E., Hoffman, L.C., 2017. Comparing the effect of age and dietary energy content on feedlot performance of Boer goats. Small Rumin. Res., 157, 40–46.

Cannas, A., Tedeschi, L.O., Fox, D.G., Pell, A.N., Van Soest, P.J., 2004. A mechanistic model for predicting the nutrient requirements and feed biological values for sheep. J. Anim. Sci., 82:149–169.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., Fourie, J.E., 2004. A comparison between the body composition, carcass characteristics and retail cuts of South African Mutton Merino and Dormer sheep. S. Afr. J. Anim. Sci., 34, 44-51.

Cloete, S.W.P., Cloete, J.J.E., Durand, A., Hoffman, L.C., 2003. Production of five Merino type lines in a terminal crossbreeding system with Dormer or Suffolk sires. S. Afr. J. Anim. Sci., 33, 223-232.

Emmans, G.C., 1989. The growth of turkeys. In: C. Nixen and T.C. Grey (eds.) Recent advances in turkey science. Butterworths, London, UK, pp. 135–165.

Emmans, G.C., 1997. A method to predict the food intake of domestic animals from birth to maturity as a function of time. J. Theor. Biol., 186,189–199.

Erasmus, L.J., Prinsloo, J., Meissner, H.H., 1988. The establishment of a protein degradability data base for dairy cattle using the nylon bag technique. 1. Protein sources. S. Afr. J. Anim. Sci., 18, 23–29.

Erasmus, L.J., Prinsloo, J., Botha, P.M., Meissner, H.H., 1990a. The establishment of a ruminal protein degradation data base for dairy cattle using the *in situ* polyester bag technique. 2. Energy sources. S. Afr. J. Anim. Sci., 20, 124–129.

Erasmus, L.J., Prinsloo, J., Botha, P.M., Meissner, H.H., 1990b. The establishment of a ruminal protein degradation data base for dairy cattle using the *in situ* polyester bag technique. 3. Roughages. S. Afr. J. Anim. Sci., 20, 130–135.

Faverdin, P., 1999. The effect of nutrients on feed intake in ruminants. Proc. Nutr. Soc., 58, 523–531.

Finlayson, J.D., Cacho, O.J., Bywater, A.C., 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agric. Syst., 48, 1–25.

Forbes, J.M., 2007. A personal view of how ruminant animals control their intake and choice of food: minimal total discomfort. Nutr. Res. Rev., 20, 132–146.

Ingvartsen, K.L., 1994. Models of voluntary food intake in cattle. Livest. Prod. Sci., 39, 19–38.

Gibson, J.P., 1981. The effects of feeding frequency on the growth and efficiency of food utilization of ruminants: an analysis of published results. Anim. Sci., 32, 275–283.

Illius, A.W., Jessop, N.S., Gill, M., 2000. Mathematical models of food intake and metabolism in ruminants, in: Cronjé P.B., (ed) Ruminant physiology, digestion, metabolism growth and reproduction (). CABI Publishing, Wallingford, UK, pp.21-40.

Johnson, I.R., France, J., Thornley, J.H.M., Bell, M.J., Eckard, R.J., 2012. A generic model of growth, energy metabolism, and body composition for cattle and sheep. J. Anim. Sci., 90, 4741–4751.

Lewis, R.M., Emmans, G.C., 2010. Feed intake of sheep as affected by body weight, breed, sex, and feed composition. J. Anim. Sci., 88: 467–480.

Marie, M., Findlay, P.A., Thomas, L., Adam, C.L., 2001. Daily patterns of plasma leptin in sheep: effects of photoperiod and food intake. J. Endocrinol., 170, 277–286.

Meissner, H.H., Hofmeyr, H.S., Van Rensburg, W.J.J. & Pienaar, J.P., 1983. Classification of livestock for realistic prediction of substitution values in terms of a biologically defined Large Stock Unit. Technical Communication 175. Department of Agriculture, Republic of South Africa.

Ministry of Agriculture, Fisheries and Food, 1975. Energy allowances and feeding systems for ruminants. Tech Bull. 33, Ministry of Agriculture and Fisheries. Her Majesty's Stationary Office, London, pp. 79.

Muir, S.K., Linden, N., Knight, M., Behrendt, R., Kearney, G., 2018. Sheep residual feed intake and feeding behaviour: are 'nibblers' or 'binge eaters' more efficient? Anim. Prod. Sci., 58, 1459–1464.

National Research Council. 2017. Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids. National Academic Press, Washington D.C., U.S.A. pp. 256–261.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci., 71, 3138-3150.

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. R. Bras. Zootec., 42, 675–690.

Thompson, J.M., Parks, J.R., 1983. Food intake, growth and mature size in Australian Merino and Dorset Horn sheep. Anim. Sci., 36, 471–479.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Tolkamp, B.J., Emmans, G.C., Kyriazakis, I., 2006. Body fatness affects feed intake of sheep at a given body weight. J. Anim. Sci., 84, 1778–1789.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019. Application of growth models to different sheep breed types in South Africa. Small Rumin. Res., 178, 70-78.

Vieira, P.A.S., Pereira, L.G.R., Azevêdo, J.A.G., Neves, A.L.A., Chizzotti, M.L., dos Santos, R.D., de Araújo, G.G.L., Mistura, C., Chaves, A.V., 2013. Development of mathematical models to predict dry matter intake in feedlot Santa Ines rams. Small Rumin. Res., 112, 78–84.

Zereu, G., 2016. Factors Affecting Feed Intake and Its Regulation Mechanisms in Ruminants A Review. Int. J. Livest. Res., 6, 19–40.

# Chapter 5 - Using Ultrasound to predict fat deposition in growing lambs of different South African sheep breed types


## Abstract

Ultrasound technology was used to measure fat and muscle tissue depth of the *longissimus* muscle for six different lamb breeds. Ram and ewe lambs from Dohne Merino, Dormer, Dorper, Meatmaster, South African Mutton Merino and White Dorper breeds were reared together under optimal feedlot management conditions, and were subjected to ultrasound scans every fortnight from the point when the lambs attained 20 kg body weight up until 300 days of age, when the lambs were assumed to have neared maturity. Exponential and linear functions were used to describe the increase in fat depth with body weight and age of the lambs, respectively as predictor. The power curve function was in turn used to describe the increase in muscle tissue depth. Moderate to good fits were achieved for the models describing the increase in fat depth of the various production groups with weight ($R^2$= 0.48-0.72) or age ($R^2$= 0.53-0.78) as predictor. Fat deposition was seen to be higher in ewes than in rams, as well as higher in hair sheep breeds compared to the wool sheep types; thus clearly defining the differences in physiological maturity of the various sexes and breeds in this study. The models describing the increase in muscle depth, presented poor to moderate fits of the data for the different production groups ($R^2$= 0.36-0.64). The models developed in this study can be used as benchmarks to be integrated into precision lamb rearing applications, to predict an ideal slaughter weight, as well as in breeding programs selecting for improved lean growth.


**Keywords:** *Fat depth; Subcutaneous; Breed; Maturity; Modelling*

## 5.1 Introduction

As lamb producers aim to meet target carcass specifications stipulated by processors and consumers (Vermeulen *et al*., 2015), improved live measurement techniques and prediction models are needed to anticipate carcass merit at a specific age and weight. Aside from age of the animal and weight of the carcass at slaughter, the level of subcutaneous fat cover is one of the main drivers in determining the value of a lamb carcass under the South African carcass classification system (Bruwer *et al*., 1987a; Webb, 2015), as well as that of the red meat industries of other countries (Sañudo *et al.,* 2000; Kosulwat *et al*., 2003). Fat is an important component that influences the juiciness, aroma, flavour and thus the eating quality of the meat, though the quantity and type of fat are considered controversial concerning health issues (Webb & O'neill, 2008). The modern consumer, who is more concerned with maintaining a healthy diet, tends to prefer a leaner cut of meat; however, they still desire a good eating experience. Aside from the colour, consumers tend to assess the quality of meat based on the amount of visible fat as an indicator of eating quality and wholesomeness (Font-i-Furnols & Guerrero, 2014). With regard to lamb and mutton, subcutaneous fat is the most visible indicator of fatness; although butchers and processors trim excess carcass fat, this practice is avoided where possible, as it is costly (Strydom *et al*., 2009). It is therefore important for producers to ideally slaughter lambs according to market specifications set for the degree of fatness to suit the consumer's acceptability, and so ensure optimal profitability throughout the market chain.

Ultrasonic technology has been proven to be a useful tool in measuring tissue depth and estimating carcass composition for genetic evaluation of live sheep in selection programs (Silva, 2017). While Bruwer *et al*. (1987b) indicated that the fat depth between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae gives the best prediction of carcass fat; an additional fat layer at this site, particularly in fatter lambs lowers the precision of scanning at this site and so scanning at the position of the 13$^{th}$ rib gives a better prediction (Thériault *et al*., 2009). The standard reference point on the *Longissimus lumborum* muscle between the 12$^{th}$ and 13$^{th}$ thoracic vertebrae has typically been implemented by breeders to determine the cross-sectional size of the eye-muscle, as well as the subcutaneous fat cover (Hopkins *et al*., 2008). Ultrasound fat depth measurements have shown to be strongly correlated (r=0.86) with carcass fat depths after lambs are slaughtered (Hopkins, 1990). High genetic correlations relating ultrasound fat depth and cross-sectional size of the eye muscle with postweaning growth, have also been reported (Mortimer *et al*., 2017). These measurements can be integrated with lamb growth data, and tissue composition so as to estimate the carcass characteristics based on the measurements on live sheep (Stanford *et al*., 2001; Hopkins *et al*., 2007). Therefore, by using ultrasound technology to measure the fat cover over the *longissimus* muscle of growing lambs on a regular basis, allows for suitable regressions to be developed that can be used to predict the level of carcass fat at a selected live weight.

Global lamb and mutton production have grown by *ca* 1.8% per year from 2010 to 2017 (FAOSTAT, 2018), with South Africa contributing around 177 000 tonnes of lamb/mutton in recent years (DAFF, 2019). The South African sheep flock consists of a variety of breeds that are diverse in their potential for wool and meat production (Cloete *et al*., 2014). These breeds also vary in maturity type and so exhibit different growth characteristics and fat deposition rates (Cloete *et al*., 2012; Brand *et al*., 2018). The Dorper breed, for instance, is renowned as being an early maturing breed and so displays higher levels of fat at a younger age or lighter body weight (Cloete *et al*., 2000). Ewe lambs also attain physiological maturity relatively earlier than castrated wethers and ram lambs in turn, respectively, and therefore have a higher degree of fatness when slaughtered at the same live weight (Arnold & Meyer, 1988). Due to these differences in maturity, lambs of different breeds or sexes must be slaughtered at different live weights in order to render carcasses with similar degrees of fatness. In order to optimise the level of production of intensive lamb rearing systems, it is necessary to be able to predict the rates of subcutaneous fat deposition of different breeds so as to determine ideal slaughter weights for optimal profitability.

In order to be able to determine fat deposition rates of growing lambs of various breeds, this study aimed to make use of ultrasound technology to measure back-fat and muscle tissue depth of growing lambs on a regular basis. Models could then be fitted to the data so as to describe subcutaneous back-fat deposition and muscle tissue growth in sheep breeds that are popular in South African commercial feedlot production systems.

## 5.2 Materials and methods

### 5.2.1 Animal management

This study was performed under the ethical clearance obtained from the Western Cape Department of Agriculture's departmental ethics committee (DECRA R14/110). Lambs from six sheep breeds, which are popular in South African production systems, were included in this study; namely the Dohne Merino, Dormer, Dorper, Meatmaster, South African Mutton Merino (SAMM) and White Dorper. Management of the resource flock consisting of these breeds on Langgewens Research Farm in the Swartland district of the Western Cape in South Africa (-33.276833, 18.704252) are described in Van der Merwe *et al*. (2019).

Lambs of the respective breeds were born during the months of May-June of the same year and were reared with their dams on wheat stubble and medics (*Medicago truncutula, Medicago littoralis* and *Medicago polymorpha*) pastures. The lambs also received creep feed (formulated primarily using wheat and full-fat canola) containing 86.9% total digestible nutrients, 18.2% crude protein, 13.5% fat, 8.4% crude fibre, 1.12% calcium and 0.74% total phosphorous, *ad libitum* from 28 days of age until they were weaned at *ca* 120 days of age. The lambs were then moved to the feedlot, were rams and ewes were separated and provided a concentrated finisher ration *ad libitum* (formulated primarily using maize, *Medicago sativa* hay and cottonseed oilcake), containing 708.0 g/kg total digestible nutrients, 10.62 MJ/kg feed metabolisable energy, 159.0 g/kg crude protein, 219.0 g/kg neutral detergent fibre, 26.0 g/kg calcium and 8.0 g/kg phosphorous. These rearing conditions were carried out to ensure the optimal uninhibited growth of lambs from birth until one year of age. During this rearing period the lambs were weighed on a weekly basis and accompanying ultrasound scan measurements were taken at two week intervals.

### 5.2.2 Ultrasound scanning

Scanning of the lambs commenced once they had attained a body weight of 20 kg, after which scans were performed on a fortnight basis until the lambs reached about one year of age, when they were assumed to have realised maturity. The subcutaneous back-fat depth of the left *longissimus lumborum* muscle was measured using a Mindray DP 30V ultrasound scanner, with a 7.5 MHz linear transducer, at the position between the $12^{th}$ and $13^{th}$ thoracic vertebrae. The wool or hair was gently combed at the scanning position, and minimal pressure was applied. Ultrasound gel was used as a coupling agent to improve conductivity between the transducer probe and the skin. At the site, the transducer was placed perpendicular to the spine, to obtain a cross-sectional image of the muscle. Once the best image was obtained, it was frozen and on-screen measurements of the cross section subcutaneous fat depth and muscle depth were taken (Mindray DP 30 digital ultrasonic diagnostic system imaging system 1.0). The measurements were taken at approximately the midpoint of the longitudinal width of the muscle, at the point where muscle depth was deepest. Ultrasound scanning was carried out by an experienced operator. Ultrasound measurements recorded up until 300 days of age were included in the database. A total of 1526 measurements for subcutaneous back-fat depth and 1360 measurements of cross-sectional muscle depth with accompanying ages and body weights was collected from 69 ewe and 63 ram lambs consisting of Dohne (7 ram and 14 ewe), Dormer (9 ram and 10 ewe), Dorper (7 ram and 14 ewe), Meatmaster (16 ram and 13 ewe), SAMM (14 ram and 6 ewe) and White Dorper (10 ram and 12 ewe) breeds.

### 5.2.3 Statistical analysis

The ultrasound measurements were regressed against the accompanying body weights and ages of the lambs at sampling. Appropriate regression equations were fitted to the data to describe the change in tissue depth with age and weight of the lambs using the PROC NLIN function of SAS Enterprise Guide (SAS version 7.1). The exponential function, in the form of $Y = A \cdot exp^{(B \cdot W)}$, where $Y$ is the fat depth (cm) at body weight $W$ *(kg)* and the coefficients $A$ and $B$ are the model parameters, was found to best describe the increase in fat depth with body weight. Due to high degrees of fatness observed in heavier lambs causing the model to overestimate fat depth using the exponential function, data for this model was limited to body weights of 20-65 kg for the lambs. This was to ensure that accurate predictions can be made during the main rearing and marketing period. On the other hand, a linear function (PROC LIN) of the form: ($Y = A + Bt$), where $Y$ denotes back-fat depth (cm) at the age $t$ (days), was found to best describe the increase in fat depth with age of the lambs. To describe the changes in cross-sectional muscle depth, the power curve of the form: $Y = A \cdot X^B$, where $Y$ denotes longissimus muscle depth (cm) at $X$ body weight (kg) or age (days), was found to be most appropriate. Analysis of variance was used to compare the main effects of breed and sex and the interaction between these effects on the model parameters of the respective functions using the general linear models procedure of SAS Enterprise Guide. Differences between the functions were tested at the $P \leq 0.05$ level and tendencies at the $P \leq 0.10$ level using the Bonferonni t-test comparison. Coefficients of determination ($R^2$) for the various nonlinear models were obtained by regressing observed and expected measurements against each other (Tedeschi, 2006).

In order to correct for the calibration of the ultrasound device, a regression was set up to determine the true tissue measurements estimated by the device by comparing ultrasound measurements of live lambs and calliper measurements of subcutaneous fat on the carcass, after the lamb had been slaughtered. In order to set up this calibration, data was collected from 310 lambs of mixed breeds that were slaughtered between 4–12 months of age with varying degrees of fatness. The back-fat depths were measured with the scanner two days prior to slaughter, as previously described. The lambs were then transported and slaughtered at nearby registered commercial abattoirs according to South African standards. After chilling for 24 hours, steaks from the left *longissimus* muscles were excised from the left side of the carcasses at the position of the 13$^{th}$ thoracic vertebrae, which is the same region which was scanned prior. The subcutaneous fat depth of the excised steak was measured using a calliper. A linear regression was fitted using SAS Enterprise Guide to describe the relationship between ultrasound fat depth and calliper fat depth to obtain the calibration correction to determine true fat depth from the ultrasound measurements.

## 5.3 Results

The exponential function was found to be most appropriate in describing the changes in fat depth of the lambs relative to body weight (Tables 5.1 and 5.2). The *A* parameter of the exponential curve represents the theoretical initial fat depth of the lamb when body weight *W* would be equal to zero. The *B* parameter represents the growth coefficient of the model; higher *B* values thus indicate higher fat deposition rates.

**Table 5.1** Comparison of the effects of sex and breed on estimates of model parameters of exponential function fitted to describe the back-fat deposition of growing lambs (20-65 kg), with body weight as a predictor.

| Main effect | | Parameter* | |
|---|---|---|---|
| | | ***A*** | ***B*** |
| Sex | Ram | 0.0760 ± 0.0057 | 0.0399 ± 0.0016 |
| | Ewe | 0.0690 ± 0.0054 | 0.0479 ± 0.0015 |
| | *P-value* | *0.401* | *<0.001* |
| Breed | Dohne Merino | 0.0767 ± 0.0099 | $0.0384^{b}$ ± 0.0028 |
| | Dormer | 0.0798 ± 0.0098 | $0.0364^{b}$ ± 0.0027 |
| | Dorper | 0.0696 ± 0.0099 | $0.0454^{ab}$ ± 0.0028 |
| | Meatmaster | 0.0700 ± 0.0081 | $0.0510^{a}$ ± 0.0023 |
| | SA Mutton Merino | 0.0664 ± 0.0104 | $0.0406^{ab}$ ± 0.0029 |
| | White Dorper | 0.0737 ± 0.0091 | $0.0515^{a}$ ± 0.0026 |
| | *P-value* | *0.936* | *<0.001* |

$^{a\text{-}c}$ Column means with different superscripts differ ($P \leq 0.05$).

*Exponential function fitted: ($Y = A \cdot exp^{(B \cdot W)}$), where $Y$ denotes back-fat depth (cm) at body weight $W$ (kg).

The parameter values of the exponential function, fitted to the back-fat depth curves, were compared between the breeds and sexes in this study (Table 5.1). No interactions were observed between the main effects of breed and sex ($P$ >0.05). The $A$ parameter values did not differ between the sexes ($P$ =0.401, while ewes presented significantly higher $B$ parameter values than rams (0.0479 and 0.0399, respectively). Figure 5.1 visually illustrates how the ultrasonic back-fat depth of ewe lambs increased with body weight at a faster rate than that of ram lambs. The $A$ parameter values did not differ between the breeds (~0.0727; $P$ =0.936). With respect to the $B$ parameter estimates of the exponential function describing fat deposition with body weight; Meatmaster and White Dorper breeds presented significantly higher values than that of the Dohne Merino and Dormer breeds (~0.0513 *vs.* ~0.0374, respectively; $P$ ≤0.05). The $B$ parameter estimates for Dorper and SAMM lambs, however, did not vary from any of the breeds (~0.0430; $P$ >0.05). The trends for the increase in back-fat depth measured ultrasonically with the increase of lamb body weight for the different breeds in this study are illustrated in Figure 5.2. The sharpest increase in fat depth is seen in Meatmaster and White Dorper lambs followed by the Dorper breed. The Dohne Merino, Dormer and SAMM breeds exhibited similar trends for the increase in fat depth, which were lower than that of the hair breeds.

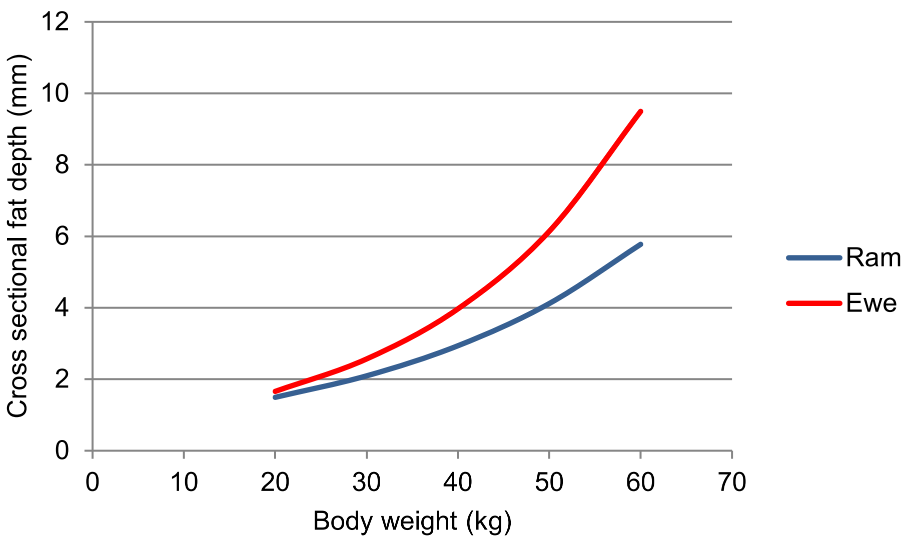


**Figure 5.1** The increase in ultrasound measured back-fat depth predicted by the exponential function for ram and ewe lambs, from various sheep breeds, reared under ideal conditions from birth to maturity.

After comparing the effects of sex and breed, it is necessary for intensive production systems to present the separate model functions for each production group along with the coefficients of determination. The model functions derived for the various production groups, where the exponential function was fitted to describe the change in back-fat depth with body weight are shown in Table 5.2. Moderate to high $R^2$ values were obtained between the observed and expected values, predicted by the models, with more than 47% of the variation being accounted for. This illustrates that these models can be used to predict the fat depth of lambs with reasonable accuracy. The highest $R^2$ values were realised for Dohne Merino and Dormer ewes and Meatmaster rams (0.723, 0.667 and 0.660, respectively). While the lowest $R^2$ values were realised for the models developed for Meatmaster ewes and Dorper rams ($R^2$ =0.469 and 0.514, respectively). Although these models only account for approximately 50% of the variation, when looking specifically at the traditional rearing weights for slaughter (between 20-50 kg), $R^2$ values >0.645 can be obtained between the observed and predicted values. Thus, these models can be applied to predict back-fat depth of lambs destined for slaughter at live weights less than 50 kg. At heavier live weights as lambs near maturity, prediction of back-fat depth may be confounded as a result of large variation in fat depth recordings.

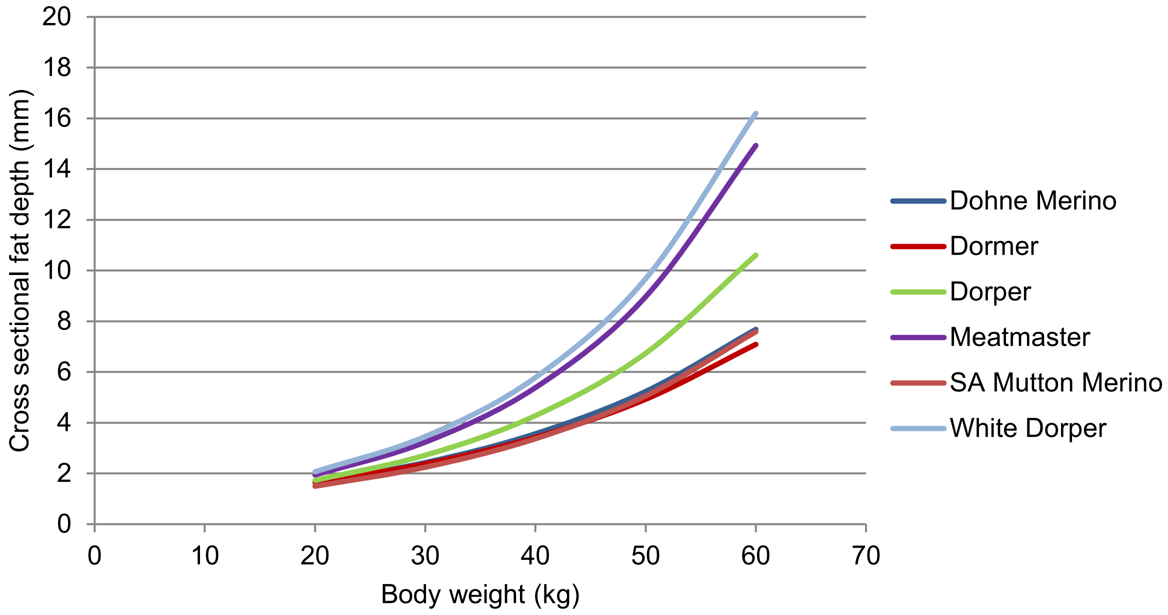


**Figure 5.2** The increase in ultrasound measured back-fat depth predicted by the exponential function for various sheep breeds reared under ideal conditions from birth to maturity.

**Table 5.2** Exponential model functions ($Y = A \cdot exp^{(B \cdot W)}$) fitted to various sheep breeds to describe back-fat deposition with the change in body weight in growing lambs, with accompanying $R^2$ values.

| Breed | Sex | Model function* | $R^2$ |
|---|---|---|---|
| Dohne Merino | Ewe | $Y$=0.0748 x $exp$(0.0426$W$) | 0.723 |
| | Ram | $Y$=0.0786 x $exp$(0.0342$W$) | 0.635 |
| Dormer | Ewe | $Y$=0.0845 x $exp$(0.0402$W$) | 0.667 |
| | Ram | $Y$=0.0751 x $exp$(0.0325$W$) | 0.620 |
| Dorper | Ewe | $Y$=0.0764 x $exp$(0.0474$W$) | 0.585 |
| | Ram | $Y$=0.0628 x $exp$(0.0435$W$) | 0.514 |
| Meatmaster | Ewe | $Y$=0.0575 x $exp$(0.0584$W$) | 0.469 |
| | Ram | $Y$=0.0825 x $exp$(0.0436$W$) | 0.660 |
| SA Mutton Merino | Ewe | $Y$=0.0743 x $exp$(0.0432$W$) | 0.588 |
| | Ram | $Y$=0.0585 x $exp$(0.0585$W$) | 0.650 |
| White Dorper | Ewe | $Y$=0.04911 x $exp$(0.0553$W$) | 0.616 |
| | Ram | $Y$=0.0984 x $exp$(0.0476$W$) | 0.554 |

*$Y$ denotes back-fat depth (cm) and $W$ denotes the body weight (kg) of the sheep.

While acceptable models were developed to predict back-fat depth from the body weight of the lambs, it was investigated whether improved models could be developed using age instead of body weight as the independent factor. A simple linear model was found to be sufficient to describe the increase in back-fat depth with age of the lambs (Tables 5.3 and 5.4). Comparison of the linear model parameters (Table 5.3) showed that the intercept ($A$)

parameter for ewes (-0.420) was lower (*P* =0.004) than that of rams (-0.304). The *A* parameter of the Meatmaster breed (-0.535) was also significantly lower than that of the Dohne Merino (-0.249), Dorper and White Dorper breeds (-0.330), while the intercepts of the Dormer and SAMM breeds did not differ from any of the other breeds (*P* >0.05). The slope parameter (*B*), indicating the rate of fat deposition with age, was higher (*P* =0.001) for ewes (0.0063) than for rams (0.0053). The *B* parameter values of Meatmaster sheep (0.0072) were higher than that obtained by Dohne Merino (0.0046), Dormer (0.0057) and White Dorper (0.0055) sheep (*P* ≤0.05). The slope parameter (*B*) of Dorper and SAMM sheep, though, did not differ from the other breeds (*P* >0.05)

**Table 5.3** Comparison of the effects of sex and breed on estimates of model parameters of linear function fitted to describe the rate back-fat deposition with age of growing lambs.

| Main effect | | Parameter* | |
|---|---|---|---|
| | | ***A*** | ***B*** |
| Sex | Ram | -0.304 ± 0.0288 | 0.0053 ± 0.0002 |
| | Ewe | -0.420 ± 0.0274 | 0.0063 ± 0.0002 |
| | *P-value* | *0.004* | *0.001* |
| Breed | Dohne Merino | -0.249$^{a}$ ± 0.0504 | 0.0046$^{b}$ ± 0.0004 |
| | Dormer | -0.370$^{ab}$ ± 0.0501 | 0.0057$^{b}$ ± 0.0004 |
| | Dorper | -0.330$^{a}$ ± 0.0504 | 0.0059$^{ab}$ ± 0.0004 |
| | Meatmaster | -0.535$^{b}$ ± 0.0407 | 0.0072$^{a}$ ± 0.0003 |
| | SA Mutton Merino | -0.359$^{ab}$ ± 0.0532 | 0.0059$^{ab}$ ± 0.0004 |
| | White Dorper | -0.330$^{a}$ ± 0.0467 | 0.0055$^{b}$ ± 0.0004 |
| | *P-value* | *<0.001* | *<0.001* |

$^{a-c}$ Column means with different superscripts differ (*P* ≤0.05).

*Linear function fitted: ($Y = A + Bt$), where $Y$ denotes back-fat depth (cm) at the age $t$ (days)

After illustrating the differences of the model parameters observed between the sexes and breeds in this study, the individual model functions describing the increase in fat depth with age, for the various production groups, can be presented to simplify prediction (Table 5.4). Generally, $R^2$ coefficients of determination were moderate to high, with the lowest value being obtained by Dohne Merino rams, where only 52.8% of the variation of the data was accounted for by the model. Conversely, the model to predict the back-fat of Dohne Merino was found to account for 78% of the variation of the data. The models fitted to the remaining production groups all accounted for more than 59% of the variation of the respective data sets, allowing for reasonably accurate predictions to be made.

**Table 5.4** Linear model functions ($Y= A + Bt$) fitted to various sheep breeds to describe back-fat deposition in growing lambs, with accompanying $R^2$ values.

| Breed | Sex | Model function* | $R^2$ |
|---|---|---|---|
| Dohne Merino | Ewe | $Y$=0.0049$t$ – 0.290 | 0.781 |
| | Ram | $Y$=0.0043$t$ – 0.208 | 0.528 |
| Dormer | Ewe | $Y$=0.0068$t$ – 0.505 | 0.739 |
| | Ram | $Y$=0.0046$t$ – 0.234 | 0.759 |
| Dorper | Ewe | $Y$=0.0062$t$ – 0.356 | 0.732 |
| | Ram | $Y$=0.0057$t$ – 0.303 | 0.751 |
| Meatmaster | Ewe | $Y$=0.0074$t$ – 0.558 | 0.714 |
| | Ram | $Y$=0.0070$t$ – 0.513 | 0.594 |
| SA Mutton Merino | Ewe | $Y$=0.0067$t$ – 0.436 | 0.686 |
| | Ram | $Y$=0.0049$t$ – 0.283 | 0.729 |
| White Dorper | Ewe | $Y$=0.0058$t$ – 0.376 | 0.654 |
| | Ram | $Y$=0.0053$t$ – 0.284 | 0.629 |

*$Y$ denotes back-fat depth (cm) and $t$ denotes the age (days) of the sheep.

A power curve was found to be most appropriate in describing the increase in cross-sectional muscle depth with body weight (Table 5.5) and age (Table 5.6). Model parameters *A* and *B* describing the change in muscle depth with body weight of the lambs (Table 5.5), showed no differences between rams and ewes for either parameter estimates of the power curve ($P$ >0.05). While muscle depth followed a similar trend between sexes, differences were however observed between breeds for the model parameter values ($P$ ≤0.05). The Dormer breed obtained the highest *A* parameter value, which was significantly greater than that of the Meatmaster breed (1.104 *vs.* 0.689, respectively). The *A* parameter values of the remaining breeds did not differ from that of any of the other breeds ($P$ >0.05). Conversely, the highest *B* parameter values were obtained by the Meatmaster breed, which was significantly higher than that of Dormer lambs (0.391, *vs*. 0.261, respectively). Again, the *B* parameter estimates of the Dohne Merino, Dorper, SAMM and White Dorper lambs, did not differ from any of the other breeds ($P$ >0.05).

**Table 5.5** Comparison of the effects of sex and breed on estimates of model parameters of power curve function fitted to describe the increase in *longissimus* muscle depth with body weight of growing lambs.

| Main effect | | Parameter* | |
|---|---|---|---|
| | | ***A*** | ***B*** |
| Sex | Ram | 0.928 ± 0.0473 | 0.305 ± 0.0166 |
| | Ewe | 0.919 ± 0.0445 | 0.336 ± 0.0156 |
| | *P-value* | *0.885* | *0.186* |
| | | | |
| Breed | Dohne Merino | $0.915^{ab}$ ± 0.0819 | $0.291^{ab}$ ± 0.0286 |
| | Dormer | $1.104^{a}$ ± 0.0839 | $0.261^{b}$ ± 0.0293 |
| | Dorper | $0.862^{ab}$ ± 0.0819 | $0.361^{ab}$ ± 0.0286 |
| | Meatmaster | $0.689^{b}$ ± 0.0660 | $0.391^{a}$ ± 0.0231 |
| | SA Mutton Merino | $1.011^{ab}$ ± 0.0863 | $0.292^{ab}$ ± 0.0302 |
| | White Dorper | $0.960^{ab}$ ± 0.0757 | $0.327^{ab}$ ± 0.0265 |
| | *P-value* | *0.004* | *0.006* |

$^{a-c}$ Column means with different superscripts vary ($P$ ≤0.05).

*Power curve function fitted: ($Y = A \cdot W^{B}$), where $Y$ denotes longissimus muscle depth (cm) at body weight $W$ (kg).

The same power curve function was used to describe the change in muscle depth with age, for the various production groups (Table 5.6). Similar trends for age were observed as for the power curves describing the increase muscle tissue with body weight. No interactions between breed and sex were observed, with the effect of sex also not influencing the *A* and *B* parameter value estimates ($P$ >0.05). The lowest *A* parameter value was estimated for Meatmaster lambs, which was lower than that of Dohne Merino, Dormer, SAMM and White Dorper lambs (0.390 *vs.* 0.741, 0.864, 0.798 and 0.746, respectively; $P$ ≤0.05). Alternatively, for the *B* parameter values, the Meatmaster lambs had the highest parameter estimate (0.458) which was significantly greater than that of the Dohne Merino, Dormer, SAMM and White Dorper lambs (0.281, 0.266, 0.293 and 0.323, respectively). Neither the *A* nor *B* estimates of Dorper lambs differed from the other breeds in this study ($P$ >0.05).

**Table 5.6** Comparison of the effects of sex and breed on estimates of model parameters of power curve function fitted to describe the increase in longissimus muscle depth with the age of growing lambs.

| Main effect | | Parameter* | |
|---|---|---|---|
| | | ***A*** | ***B*** |
| Sex | Ram | 0.659 ± 0.0504 | 0.336 ± 0.0212 |
| | Ewe | 0.708 ± 0.0474 | 0.329 ± 0.0199 |
| | *P-value* | *0.481* | *0.790* |
| | | | |
| Breed | Dohne Merino | $0.741^{a}$ ± 0.0871 | $0.281^{b}$ ± 0.0366 |
| | Dormer | $0.864^{a}$ ± 0.0893 | $0.266^{b}$ ± 0.0375 |
| | Dorper | $0.562^{ab}$ ± 0.0871 | $0.371^{ab}$ ± 0.0366 |
| | Meatmaster | $0.390^{b}$ ± 0.0703 | $0.461^{a}$ ± 0.0295 |
| | SA Mutton Merino | $0.798^{a}$ ± 0.0918 | $0.293^{b}$ ± 0.0386 |
| | White Dorper | $0.746^{a}$ ± 0.0806 | $0.323^{b}$ ± 0.0339 |
| | *P-value* | *<0.001* | *<0.001* |

$^{a-c}$ Column means with different superscripts vary ($P \leq 0.05$).

*Power curve function fitted: ($Y = A \cdot W^{B}$), where $Y$ denotes longissimus muscle depth (cm) at the age $t$ (days).

The above power curves to describe the increase of muscle tissue depth using body weight or age as predictors were expressed for each of the production groups so as to determine the fit of the models (Table 5.7). Better fits were realised when weight was used as a predictor rather than age, however, generally the $R^2$ values describing the fits of the various models were moderate to low. The power curve with body weight as predictor for White Dorper rams accounted for a low portion of the variation of the data of the production group ($R^2$ =0.356), while the highest $R^2$ value was observed for curve fitted to Meatmaster rams. The power curves fitted to the muscle depth with age accounted for less than 45% of the variation of the data from the respective production groups. The use of age to predict muscle tissue depth is thus deemed to be a less suitable predictor.

**Table 5.7** Power curve model functions ($Y= A{\cdot}X^{B}$) fitted to various sheep breeds to describe back-fat deposition in growing lambs using either body weight (*W*) or age (*t*) as predictors, with accompanying $R^2$ values.

| Breed | Sex | Weight | $R^2$ | Age | $R^2$ |
|---|---|---|---|---|---|
| Dohne Merino | Ewe | $Y= 0.899{\cdot}W^{0.304}$ | 0.493 | $Y= 0.790{\cdot}t^{0.253}$ | 0.418 |
| | Ram | $Y= 0.931{\cdot}W^{0.278}$ | 0.437 | $Y= 0.693{\cdot}t^{0.308}$ | 0.185 |
| Dormer | Ewe | $Y= 1.172{\cdot}W^{0.252}$ | 0.373 | $Y= 0.903{\cdot}t^{0.258}$ | 0.287 |
| | Ram | $Y= 1.037{\cdot}W^{0.270}$ | 0.519 | $Y= 0.826{\cdot}t^{0.274}$ | 0.407 |
| Dorper | Ewe | $Y= 0.752{\cdot}W^{0.415}$ | 0.567 | $Y= 0.477{\cdot}t^{0.419}$ | 0.471 |
| | Ram | $Y= 0.973{\cdot}W^{0.307}$ | 0.570 | $Y= 0.648{\cdot}t^{0.323}$ | 0.374 |
| Meatmaster | Ewe | $Y= 0.684{\cdot}W^{0.391}$ | 0.499 | $Y= 0.392{\cdot}t^{0.442}$ | 0.413 |
| | Ram | $Y= 0.694{\cdot}W^{0.390}$ | 0.643 | $Y= 0.388{\cdot}t^{0.480}$ | 0.431 |
| SA Mutton Merino | Ewe | $Y= 1.116{\cdot}W^{0.292}$ | 0.404 | $Y= 0.943{\cdot}t^{0.274}$ | 0.391 |
| | Ram | $Y= 0.905{\cdot}W^{0.292}$ | 0.550 | $Y= 0.653{\cdot}t^{0.313}$ | 0.449 |
| White Dorper | Ewe | $Y= 0.891{\cdot}W^{0.359}$ | 0.441 | $Y= 0.745{\cdot}t^{0.325}$ | 0.270 |
| | Ram | $Y= 1.030{\cdot}W^{0.295}$ | 0.356 | $Y= 0.747{\cdot}t^{0.321}$ | 0.492 |

In Power curve function, *Y* denotes back-fat depth (cm) and *t* denotes the age (days) of the sheep.

For the correction of ultrasound measurements, the linear model of $y$=1.8531$x$-0.1029 ($R^2$ =0.730), where $x$ is the ultrasound fat depth and $y$ is the actual fat depth, was derived between measured and actual fat depths. This regression can be incorporated with the above models in order to determine the actual fat depth from the predicted fat depth with reasonably high accuracy.

## 5.4 Discussion

The role of a feedlot finishing or fattening system is to add value to the carcass of a lamb with a light body weight and poor conformation in order to obtain a carcass with more desirable conformation and fat cover, through managing the growth and nutrition of the lamb. The lambs in this study were reared under optimal growth conditions and were fed a balanced diet that was formulated to sustain high levels of growth. This diet also resembles the specifications of commercial feedlot diets that lambs are typically finished on (National Research Council, 2017). Under these optimal conditions, the lambs of the various breeds were allowed to grow uninhibited according to their genetic potential. As the lambs were allowed to exhibit high growth rates according to their potential; growth in the form of fat deposition was also allowed as excess energy not required for maintenance, muscle growth and movement could be stored in the adipose tissues. This thus illustrates the potential of the breeds to deposit fat at rates relative to their growth potential. The use of ultrasound technology made it possible to track the rates of subcutaneous back-fat deposition as the lambs grew. This allowed for models to be fitted to the fat deposition curves of the various breeds which can be used to predict the fat depth of lambs before they are slaughtered. Hamlin *et al.* (1995) found that ultrasonic fat depth in feedlot steers increased linearly with body weight up until about 457 days of age (580 kg live weight). With only 46% of the variation of the data being accounted for when fitting a quadratic function, Hamlin *et al.* (1995) proposed using an exponential function when fat depth measurements from heavier and fatter animals are included in the dataset. In the current study, consecutive ultrasound measurements taken on a regular basis were considered up until a cut-off age of 300 days, when lambs from all of the production groups already had attained high levels of fatness. Teixeira *et al*. (2006) also suggested that a logarithmic relationship was shared between body weight and carcass fat measurements. The trends observed between subcutaneous fat depth and body weight of the lambs in the current study resembled the findings above, confirming that the use of the exponential function, which revealed the best fit, is relevant in modelling these changes in fat depth of growing lambs.

Ultrasound technology is widely used in sheep production; from symptom and pregnancy diagnosis, measuring traits included in breeding programs as well as predicting lamb carcass composition (Hopkins, 1990; Gilmour *et al*., 1994; Scott, 2017). Multiple studies have been performed to determine correlations between ultrasound measurements and carcass measurements using different devices on different breeds (Hopkins *et al*., 1996; Stanford *et al*., 2001; Silva *et al.,* 2005; Grill *et al.,* 2015). It has also been shown that prediction of carcass composition of heavy lambs (86 kg) using ultrasound scans can be achieved with the same accuracy as that of light lambs (Hopkins *et al*., 2007). The correlations obtained in these studies closely resemble that of the correction factor acquired in the current study from regressing ultrasound fat depth measurements with carcass fat measurements recorded after slaughter ($R^2$ =0.730). This regression accounts for the error of the device's internal calliper and should be used to adjust ultrasound scan measurements to actual depth values. As shown by correlation studies between ultrasound measurements and carcass measurements, using different ultrasound devices, the linear regressions to predict carcass tissue depths vary (Hopkins, 1990; Gilmour *et al*., 1994; Grill *et al.,* 2015); therefore, it may be necessary to determine a calibration regression for the device to account for measurement errors.

Prior to this study, regular monitoring of back-fat depth in growing lambs has not been reported, particularly for South African breeds reared under optimal growth conditions. Subcutaneous fat depth of the *longissimus* muscle has been seen to be a reliable predictor of carcass composition in lambs (Bruwer *et al*., 1987b; Silva *et al*., 2005), and is often incorporated in carcass classification systems in order to determine the value of the carcass. Therefore, it is important to be able to understand the underlying trends in fat deposition so as to be able to decide upon an optimal fat thickness to achieve the required carcass fat score at slaughter. In the South African red meat industry, the market is driven to produce a lamb carcass with a back-fat cover of 1-4 mm (Government Notice R. 863 of 2006). The diverse variety of breeds in South Africa range in maturity types, with some breeds starting to deposit fat earlier than other breeds. Previous studies have shown that ewe lambs mature earlier than ram lambs and are thus fatter when slaughtered at the same live weight (Arnold & Meyer, 1988); with the same trends depicted in Figure 5.1, with the fat depths of ewes increasing at a higher rate than that of rams. Figure 5.2 depicts the differences in fat deposition rates of the various breeds in this study, with the hair sheep breeds showing higher levels of fat deposition relative to the Dormer, Dohne Merino and SAMM breeds. South African hair sheep breeds, bred from indigenous fat-tailed and fat-rumped breeds, were developed to survive and produce under arid and semi-arid conditions, and tend to deposit higher levels of carcass fat at lighter live weights (Cloete *et al*., 2000; Almeida, 2011). It has been postulated that the higher levels of fat deposition in these breeds is related to the survival of these animals under arid conditions with the energy stored in adipose tissue being relied on during times of scarcity (Epstein, 1960). These higher levels of fat deposition present a drawback in intensive rearing systems, as these lambs are slaughtered at lighter body weights to achieve the desired fat score which results in a smaller carcass (Brand *et al*., 2018).

As the lambs in this study were reared under optimal growth conditions, with access to feed being non-limiting, age and body weight of the lambs are closely related (Van der Merwe *et al*., 2019). Therefore, under these circumstances, ultrasound back-fat depth could be modelled with age or body weight as predictors. In both instances, the rates of fat deposition in hair sheep breeds was higher than the wool breeds, indicating that Meatmaster, Dorper and White Dorper can be considered as early maturing breeds that partition nutrients in adipose tissue at an earlier age and lighter body weight than Dohne Merino, Dormer and SAMM lambs. The Meatmaster, being a relatively novel composite breed (Peters *et al*., 2010), has not been studied as extensively compared to the other breeds that have been included in this study. While the Dorper is renowned as an early maturing breed (Cloete *et al*., 2000), the Meatmaster does exhibit higher levels of fat deposition at the same live weight (Figure 5.2). This suggests that comparatively, the Meatmaster is even earlier maturing than the Dorper breed. It has been seen that fat-tailed breeds such as the Damara, which is a precursor to the Meatmaster, do present higher fat levels of fat deposition than Dorper sheep, showing that they are also early maturing (Tshabalala *et al*., 2003). When using body weight as a predictor, Dohne Merino, Dormer and SAMM lambs show similar trends in fat deposition. However, when using age as a predictor, Dormer and SAMM lambs tend to express similar rates of fat deposition, while fat depth of Dohne Merino lambs increases at a slower rate (Table 5.3). This may be due to the fact that SAMM lambs grow faster relative to Dohne Merino lambs (Cloete *et al*., 2001); therefore, SAMM lambs may achieve maturity relatively earlier, chronologically, than Dohne

Merino lambs. It has been reported that Dormers present higher fat depths than Dohne Merino and SAMM breeds, slaughtered at the same age (Cloete *et al*., 2004; Cloete *et al*., 2012). Cloete *et al*. (2012) also observed higher fat depths in mature SAMM sheep than in Dohne Merino and Merino sheep, of similar ages, along with heavier slaughter weights. Brand *et al.* (2018) also indicated that the fat depth of SAMM lambs increased at a faster rate than that of Merino lambs with longer periods under feedlot conditions. While the Dohne Merino and SAMM are both descendants of the German Mutton Merino, bred for dual-purpose production, the SAMM breed does show more emphasis toward meat production rather than wool production as does the Dohne Merino; the latter produces a heavier fleece than the SAMM, with a lower fibre diameter resembling that of the Merino (Cloete *et al.*, 2001). The mature weights of SAMM sheep are heavier than that of Dohne Merino sheep (Van der Merwe *et al*., 2019); with the increased muscle growth in animals with heavier mature weights, the onset of fat deposition occurs at a later stage (Owens, *et al*., 1993). Therefore, when comparing at the same body weight SAMM sheep are later maturing, consisting of less fat tissue, than the bodies of Dohne Merino sheep. The Dohne Merino in turn is expected to be early maturing relative to the Merino breed which has been shown to be a later maturing breed with slower growth characteristics (Brand *et al*., 2018). The Merino breed plays a dominant role in the South African wool and lamb industries (Cloete *et al*., 2014) and models are still required to improve the prediction of carcass fat depth in the model proposed by Brand *et al*. (2018), by making use of ultrasound measurements.

Many selection programs take the size of the eye-muscle (*longissimus thoracis et lumborum*) into account as an indication of the animal's conformation and lean meat production potential. Typical measurements that are then included are the depth and width of the muscle, and area of the cross-sectional image of the *longissimus* muscle. However, the best correlations have been obtained when using muscle depth (Stanford *et al*., 1995). Modelling muscle depth measured using ultrasound in the current study was achieved with varying accuracies ranging from 35-64% of the variation of the data being accounted for in the various production groups. Scanning muscle depth in this study proved to be more difficult than fat depth, as combing of the hair of Dorper and Meatmaster lambs at the scanning site presented a complication, reducing visibility. Also, at high degrees of fatness, visibility of the muscle scan was reduced which made the judgement of tissue boundaries more difficult. Hopkins (1990) and Silva *et al*. (2017) also reported difficulties in interpreting scans, as additional layers of fat being deposited complicated the identification of tissue boundaries. It should be noted that the ultrasound device used by Hopkins (1990) was not able to provide real time measurements, which further complicated the identification of tissue boundaries.

Plotting the models of ultrasound muscle depth with body weight shows that between 20-60 kg body weight, muscle depths only vary by about 1 cm which is a relatively narrow margin to model. A negative correlation between muscle area and carcass length has been reported by Hopkins *et al*. (1993) which suggests that the *longissimus* muscle tends to grow in length at a faster rate rather than cross-sectional depth as the lamb increases in size. Extrapolation of the power curve in the current study suggests that higher growth rates of *longissimus* muscle depth are achieved between birth and 20 kg rather than at body weights greater than 20 kg, as used in this study. By incorporating these extremes (measurements taken <20 kg) into the dataset, it should be possible to fit more applicable models (Hopkins, 1990). The models in this study, though, do serve as a benchmark that can be used to correct muscle depth scan measurements taken from lambs at different body weights. This will then allow for better comparisons to be made at a standard reference weight or age. The models developed also illustrate that there are differences in the rates that muscle depth increases in these different South African breeds (Tables 5.5 and 5.6). While there are no differences between rams and ewes, Meatmaster lambs seem to have smaller initial muscle depths to Dormer, SAMM and White Dorper lambs (considering the *A* parameter estimates of the power curves; Table 5.7). As the lambs then grow towards maturity, the muscle depths of the hair sheep breeds increase at faster rates than that of the wool sheep breeds.

As mentioned, ultrasound measurements have previously been used as predictors of carcass quality, and have also been incorporated into breeding programs to select for enhanced lean growth (Kvame & Vangen, 2007). The purpose of this study was to develop models to predict back-fat and muscle depth, which can be integrated with precision livestock applications for lamb growth. In order to predict the value of a carcass at slaughter it is necessary to be able to predict the fat cover of a lamb carcass. This is of particular importance when lambs of different breeds are grouped together in a feedlot and optimal slaughter weights need to be predetermined. This will benefit lamb producers in maximising profit margins and reduce the risk of carcasses being classed as overfat which reduces the efficiency and sustainability and profit of lamb production. Muscle depth is not currently used as a predictor of carcass quality as carcass weight and fat depth give a better indication of saleable meat yield (Hopkins *et al*., 1996; Grill *et al*., 2015). Therefore, the models describing the increase in muscle depth have little value in terms of predicting carcass conformation, but can still be used for predictions in breeding programs. It is suggested that fat depth and muscle depth should be combined as an index to give better predictions, as well as give a more holistic selection criterion when aiming to improve lean growth.

## 5.5 Conclusion

Ultrasound scans were used to develop a database of continuous measurements to describe the increase in tissue depth in growing lambs of different breeds. Exponential and linear models were developed to describe the increase of back-fat depth of various sheep breeds with body weight and age with moderate to good accuracies. These models also demonstrated the differences in physiological maturity of the different breeds, with hair breeds such as the Dorper, White Dorper and Meatmaster being early maturing, followed by the Dormer and SAMM breeds and the Dohne Merino being later maturing.

The increase in *longissimus* muscle depth for growing lambs was modelled with low to moderate success using the power curve function. The models for the various production groups can be integrated into precision rearing and breeding applications. Increased use of ultrasound technology in intensive sheep production systems is recommended and non-genetic factors influencing the rate of fat deposition in lambs need to be investigated using ultrasound scans.

## References

Almeida, A.M., 2011. The Damara in the context of Southern Africa fat-tailed sheep breeds. Trop. Anim. Health Prod., 43,: 1427-1441.

Arnold, A.M., Meyer, H.H., 1988. Effects of gender, time of castration, genotype and feeding regimen on lamb growth and carcass fatness. J. Anim. Sci., 66: 2468-2475.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci., 47, 477-488.

Bruwer, G.G., Grobler, I., Smit, M., Naudé, R.T., Vosloo, W.A., 1987a. An evaluation of the lamb and mutton carcass grading system in the Republic of South Africa. 4. The influence of age, carcase mass and fatness on meat quality characteristics. S. Afr. J. Anim. Sci., 17, 95-103.

Bruwer, G.G., Naudé, R.T., Vosloo, W.A., 1987b. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 3. Fatness score, conformation score and carcase mass as predictors of carcase composition. S. Afr. J. Anim. Sci., 17, 90-94.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., Fourie, J.E., 2004. A comparison between the body composition, carcass characteristics and retail cuts of South African Mutton Merino and Dormer sheep. S. Afr. J. Anim. Sci. 24, 44-51.

Cloete, J.J.E., Hoffman, L.C. and Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. *Meat Sci.*, 91: 318-324.

Cloete, S.W.P., Olivier, J.J., Sandenbergh, L., Snyman, M.A., 2014. The adaption of the South Africa sheep industry to new trends in animal breeding and genetics: A review. S. Afr. J. Anim. Sci., 44, 307-321.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V. (2001). Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric., 41, 145-153.

Cloete, S.W.P., Snyman, M.A., Herselman, M.J., 2000. Productive performance of Dorper sheep. Small Rumin. Res., 36, 119-135.

Department of Agriculture, Forestry & Fisheries. 2019. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63. (https://www.daff.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202019.pdf?timestamp=1568549611726 ).

Epstein, H., 1960. History and origin of the Ronderib and Namaqua Afrikaner sheep. J. Anim. Breed. Genet., 74, 267-292.

FAOSTAT. 2018. Food and Agriculture Organization of the United Nations, Statistics Division. http://www.fao.org/faostat/en/#data/QA (Accessed June 2019).

Font-i-Furnols, M., Guerrero, L., 2014. Consumer preference, behaviour and perception about meat and meat products: An overview. Meat Sci., 98, 361-371.

Gilmour, A.R., Luff, A.F., Fogarty, N.M., Banks, R., 1994. Genetic parameters for ultrasound fat depth and eye muscle measurements in live Poll Dorset sheep. Aust. J. Agric. Res., 45, 1281-1291.

Government Notice No. R. 863 of 1 September 2006. Agricultural product standards Act 119 of 1990. Regulations regarding the classification and marketing of meat in the Republic of South Africa.

Grill, L., Ringdorfer, F., Baumung, R., Fuerst-Waltl, B., 2015. Evaluation of ultrasound scanning to predict carcass composition of Austrian meat sheep. Small Rumin. Res., 123, 260-268.

Hamlin, K.E., Green, R.D., Perkins, T.L., Cundiff, L.V., Miller, M.F., 1995. Real-time ultrasonic measurement of fat thickness and longissimus muscle area: I. Description of age and weight effects. J. Anim. Sci., 73, 1713-1724.

Hopkins, D.L., 1990. The use of ultrasound to predict fatness in lambs. Meat Sci. 27, 275-281.

Hopkins, D. L., Hall, D. G., Luff, A. F., 1996. Lamb carcass. 3. Describing changes in carcasses of growing lambs using real-time ultrasound and the use of these measurements for estimating the yield of saleable meat. Aust. J. Exp. Agric., 36, 37-43.

Hopkins, D.L., Pirlot, K.L., Roberts, A.H.K., Beattie, A.S., 1993. Changes in fat depths and muscle dimensions in growing lambs as measured by real-time ultrasound. Aust. J. Exp. Agric., 33. 707-712.

Hopkins, D.L., Ponnampalam, E.N., Warner, R.D., 2008. Predicting the composition of lamb carcases using alternative fat and muscle depth measures. Meat Sci., 78, 400-405.

Hopkins, D.L., Stanley, D.F., Ponnampalam, E.N., 2007. Relationship between real-time ultrasound and carcass measures and composition in heavy sheep. Aust. J. Exp. Agric., 47, 1304-1308.

Kosulwat, S., Greenfield, H., James, J., 2003. Lipid composition of Australian retail lamb cuts with differing carcass classification characteristics. Meat Sci., 65, 1413-1420.

Kvame, T., Vangen, O., 2007. Selection for lean weight based on ultrasound and CT in a meat line of sheep. Livest. Sci., 106, 232-242.

Mortimer, S.I., Hatcher, S., Fogarty, N.M., van der Werf, J.H.J., Brown, D.J., Swan, A.A., Greeff, J.C., Refshauge, G., Edwards, J.H., Gaunt, G.M., 2017. Genetic parameters for wool traits, live weight, and ultrasound carcass traits in Merino sheep. J. Anim. Sci., 95, 1879-1891.

National Research Council. 2017. Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids. National Academic Press, Washington DC., U.S.A. pp 256-261.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci., 71, 3138-3150.

Peters, F.W., Kotze, A., Van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res., 90, 101-108.

Sañudo, C., Alfonso, M., Sánchez, A., Delfa, R., Teixeira, A., 2000. Carcass and meat quality in light lambs from different fat classes in the EU carcass classification system. Meat Sci., 56, 89-94.

Scott, P.R., 2017. Use of ultrasonographic examination in sheep health management—A general appraisal. Small Rumin. Res., 152, 2-9.

Silva, S.R., 2017. Use of ultrasonographic examination for in vivo evaluation of body composition and for prediction of carcass quality of sheep. Small Rumin. Res., 152, 144-157.

Silva, S.R., Gomes, M.J., Dias-da-Silva, A., Gil, L.F., Azevedo, J.M.T.D., 2005. Estimation in vivo of the body and carcass chemical composition of growing lambs by real-time ultrasonography. J. Anim. Sci., 83, 350-357.

Stanford, K., Bailey, D.R.C., Jones, S.D.M., Price, M.A., Kemp, R.A., 2001. Ultrasound measurement of longissimus dimensions and back-fat in growing lambs: effects of age, weight and sex. Small Rumin. Res., 42, 189-195.

Stanford, K., Clark, I., Jones, S. D. M. (1995). Use of ultrasound in prediction of carcass characteristics in lambs. Can. J. Anim. Sci., 75, 185-189.

Strydom, P.E., Van Heerden, S.M., Van Heerden, H.C., Kruger, R., Smith, M.F., 2009. The influence of fat score and fat trimming on primal cut composition of South African lamb. S. Afr. J. Anim. Sci., 39, 233-242.

Tedeschi, L.O., 2006. Assessment of the adequacy of mathematical models. Agric. Syst., 89, 225-247.

Teixeira, A., Matos, S., Rodrigues, S., Delfa, R., Cadavez, V., 2006. In vivo estimation of lamb carcass composition by real-time ultrasonography. Meat Sci., 74, 289-295.

Thériault, M., Pomar, C., Castonguay, F. W., 2009. Accuracy of real-time ultrasound measurements of total tissue, fat, and muscle depths at different measuring sites in lamb. J. Anim. Sci., 87 1801-1813.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., De Kock, H.L., 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Sci., 65, 563-570.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019. Application of growth models to different sheep breed types in South Africa. Small Rumin. Res., 178, 70-78.

Vermeulen, H., Schönfeldt, H.C., Pretorius, B., 2015. A Consumer perspective of the South African red meat classification system. S. Afr. J. Anim. Sci., 45, 339-354.

Webb, E.C., O'neill, H.A., 2008. The animal fat paradox and meat quality. Meat Sci., 80, 28-36.

Webb, E.C., 2015. Description of carcass classification goals and the current situation in South Africa. S. Afr. J. Anim. Sci., 45, 229-233.

# Chapter 6 - Premium lamb production of different South African sheep breed types under feedlot conditions


## Abstract

With the increase in number of producers opting to finish their lambs for market in on-farm feedlots, detailed production performance information is required to implement precision finishing of lambs of different genotypes. In this study, the feedlot production characteristics of ram and ewe lambs from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, Namaqua Afrikaner and South African Mutton Merino (SAMM) breeds were evaluated. The lambs were intensively reared together under feedlot conditions, where they were fed the same diet (10.41 MJ ME/kg feed and 190.6 g/kg crude protein) and their feed intake and weekly growth monitored, from an initial weight of 30 kg until they achieved the desired subcutaneous fat cover to produce an A2 lamb carcass. Subcutaneous fat was measured on the *longissimus* muscle using an ultrasound scanner to determine the point at which the lambs were slaughter ready, according to the level carcass fat cover. Early maturing breeds (Dorper and fat-tailed breeds) had the shortest rearing periods in the feedlot and were market ready at a lower live weight ($P \leq 0.05$). As a result, these lambs consumed less feed in the feedlot; however, Namaqua and Merino lambs presented the most unfavourable feed conversion ratios (7.08 and 5.63 kg feed/kg weight gain, respectively). The most favourable feeding efficiencies were observed in Dohne Merino, Dormer, Dorper and Meatmaster rams, as well as Dorper ewes, (~3.58 kg feed/ kg weight gain), with Dohne Merino and Dormer rams attaining the highest growth rates (~465 g/day). The end weights described in this study, can be used as an indication for producers of the ideal slaughter weights for the breeds of different maturity types.

**Keywords:** *Average daily gain; Feed efficiency; Fat deposition; Rearing period*

## 6.1 Introduction

Vast semi-arid and arid regions within southern Africa (South Africa and Namibia) are unsuitable for agricultural practices, with the exception of extensive sheep production, as sheep are well adapted to these conditions (Brand, 2000). With income generated from meat as well as wool production, the South African sheep industry is made up of a spectrum of breeds that are classed as wool-, dual-purpose or meat types as well as indigenous fat-tailed breeds, totalling to about 19.9 million head of sheep (DAFF, 2019). According to the National Small Stock Improvement scheme, the most popular breeds in commercial production systems, based on the number of weaning weight records, are the Merino, Dohne Merino, Dorper followed by the SA Mutton Merino (SAMM) and Dormer breeds (Cloete & Olivier.

2010). The Merino is regarded as a predominant wool type breed, while dual-purpose breeds are either orientated towards wool (Dohne Merino) or meat (SAMM) production. The Dohne Merino, SAMM as well as the terminal sire Dormer breed were all developed from crossbreeding with the German Mutton Merino as a sire or dam line (Cloete *et al*., 2001; Van Wyk *et al*., 2003). The Dorper was developed from Dorset as well as Blackhead Persian breeds to obtain a sheep that can survive and produce under semi-arid conditions (Milne, 2000). The Meatmaster is a more recent composite fat-tailed breed, with predominantly Damara lineage, that was developed for commercial lamb production in extensive arid conditions (Peters *et al*., 2010). The Namaqua Afrikaner is regarded as an unimproved indigenous fat-tailed breed with a low mature weight, which is tolerant to harsh environmental conditions (Qwabe *et al*., 2013). These breeds all vary in their capacity for meat or wool production as well as their growth and maturity characteristics.

With increases in lamb and mutton prices, as well as increased pressure to intensify production systems, many producers are opting to finish their lambs in feedlots to get them market ready for slaughter. The role of feedlot finishing is to take advantage of the superior growth rates and feeding efficiencies of young animals by rearing them to a desirable market weight for optimal profitability. Feedlot operators aim to produce a carcass of an optimal weight and fat cover so as to generate maximal income; the latter plays a key role in the Namibian and South African carcass classification systems (Government notice No. R. 863, 2006). Feedlot operators often tend to prejudice against finishing early maturing breeds, such as the Dorper, as they tend to deposit fat at an earlier age and must thus be slaughtered at a lighter live weight (Brand *et al*., 2018), thereby reducing the income per carcass. However, in harsher climatic regions where these more indigenous early maturing breeds are predominantly used in production systems and at times when there is a high demand for lamb; operators may have to make the decision to enter these lambs in the feedlot.

From the viewpoint of a lamb producer, it is important to meet the market specifications for lamb in order to sustain optimum profitability. According to the Red Meat Producers Organisation (2019) of South Africa, 72% of sheep slaughtered in commercial abattoirs are regarded as premium lamb, with a carcass subcutaneous fat cover of 1-4 mm (Government notice No. R. 863, 2006), for which the highest carcass prices are obtained. When considering that lambs of different breeds start to deposit fat at different stages as well as exhibit different growth capacities, it is important to implement precision finishing in maintaining production sustainability. An ideal slaughter weight of lambs of different breeds is needed to ensure that a premium lamb carcass is still achieved. Precision finishing incorporates monitoring of growth, intake and efficiency so as to regulate and optimise management practices. In order to ensure product quality in terms of carcass quality, the use of ultrasound technology can be implemented to determine subcutaneous fat cover (Houghton & Turlington, 1992) instead of using body weight, rearing length or subjective measurements to determine when lambs are suitable for slaughter. Information on the rearing characteristics of different breeds and conditions can also be compiled in decision support systems, or feedlot calculators, so that accurate simulations can be performed in order to determine the most profitable production protocol which must be followed.

The aim of this study is to compare the feedlot production characteristics of ewe and ram lambs of seven South African sheep breeds up until an ideal slaughter weight with the desired level of fat cover (1-4 mm subcutaneous fat measured at the 13$^{th}$ rib and rump regions of the *Longissimus lumborum* muscle). In order to determine the ideal slaughter weight, this study makes use of ultrasound scans to measure back-fat and so indicate the ideal point of slaughter.

## 6.2 Materials and methods

### 6.2.1 Flock management

The experimental procedures followed in this study were approved by the Departmental Ethics Committee of Research on Animals (DECRA 14/110) of the Western Cape Department of Agriculture. This study investigated the feedlot production characteristics of ram and ewe lambs of different breeds to reach a slaughter weight with ideal fat cover. The breeds included the Dohne Merino (ewe =10, ram =6), Dormer (ewe =5, ram =5), Dorper (ewe =6, ram =8), Meatmaster (ewe =12, ram =12), Merino (ewe =6, ram =6), Namaqua Afrikaner (ewe =8, ram =6) and SAMM (ewe =4, ram =6). Lambs for the trial were obtained from the same resource flock consisting of the above breeds which were herded together under the same conditions. These resource flocks are kept on Langgewens Research farm of the Western Cape Department of Agriculture in the Swartland district of the Western Cape (coordinates: -33.276833, 18.704252). The ewes are maintained on cereal stubble and medics pastures (*Medicago truncutula, Medicago littoralis* and *Medicago polymorpha*). The ewes were synchronised and mated with rams from their respective breeds. Lambing occurred during the wet winter months of May-June. Lambs had *ad libitum* access to creep feed (86.9% total digestible nutrients, 182.0 g/kg crude protein, 135.0 g/kg fat, 84.0 g/kg crude fibre, 11.2 g/kg calcium and 7.4 g/kg total phosphorous) before weaning. The tails of Dohne Merino, Dormer, Dorper, Merino and SAMM lambs were docked at 2 weeks of age, while that of Meatmaster and Namaqua lambs were left intact, as is the commercial practise. The lambs were weighed on a weekly basis.

### 6.2.2 Feedlot production

For this trial, lambs of the respective breeds were weaned as they attained a body weight of 30 kg. However, as Namaqua Afrikaner sheep have a lower mature body weight and grow at a slower rate, the Namaqua lambs were weaned at an average weight of 27.7 kg ± 0.50. The average starting weight of the lambs from the other breeds was 30.6 kg ± 0.20. The lambs were then housed in individual pens (1 m x 2 m) at the Elsenburg Research Farm (Western Cape Department of Agriculture), so as to monitor individual growth and feed intake. Upon introduction to the intensive feeding facility, the lambs were drenched against internal parasites, and for the first three days the lambs were dosed with 0.1 g virginiamycin to help adapt them to the concentrate diet. The lambs were gradually adapted from a hay ration to a pelleted concentrate diet over a period of seven days. The lambs were then supplied the feedlot concentrate diet *ad libitum* with bunkers being topped up in the mornings and afternoons daily. The composition of the feedlot diet supplied to the lambs is presented in Table 6.1. Lambs had free access to water during the feeding period.

Feed refusals were weighed once a week at the same time each week in order to determine weekly feed intake. At this point, the lambs were also weighed in order to determine growth and their back-fat thickness was scanned using a Mindray DP30V ultrasound scanner (Shenzhen Mindray Bio-medical Electronics Co., Ltd.) with a 7.5MHz linear transducer. Ultrasound measurements were taken on the subcutaneous fat of the left *longissimus lumborum* muscle at the positions of the 13$^{th}$ rib and between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae (rump) at the midpoint of the transverse muscle. At scanning, the wool or hair at these positions was combed to provide a scanning area for the transducer. The lambs were reared under these feeding conditions until they achieved a subcutaneous fat thickness that correlates with a carcass fat score of 2 (Government notice No. R. 863, 2006). The conversion formulae derived by Van der Merwe *et al*., (2019a): $US = 0.392F + 0.3631$, $R^2$= 0.726 (where $US$ is the ultrasound measurement and $F$ is carcass fat depth, in cm) was used to calculate that for a carcass fat score of 2 with a standard subcutaneous depth (on the carcass) of 4 mm, an ultrasound measurement of 0.52cm was required. Lambs were then deemed as slaughter ready and removed from the feedlot when back-fat measurements of 5.2 ± 0.5 mm were recorded.

**Table 6.1** Ingredient formulation and nutritional composition of the feedlot diet fed to lambs.

| **Ingredient** | **Inclusion (g/kgAs fed)** |
|---|---|
| Maize | 500.0 |
| Lucerne hay | 361.0 |
| Cottonseed oilcake | 50.0 |
| Molasses powder | 25.0 |
| Ammonium chloride | 5.0 |
| Ammonium sulphate | 50 |
| Lime | 5.0 |
| Monocalcium phosphate | 5.0 |
| Common salt | 10.0 |
| Urea | 5.0 |
| Sodium Bicarbonate | 10.0 |
| Slaked lime | 5.0 |
| Sulphur | 2.0 |
| Vitamin and mineral premix | 1.5 |
| Commercial growth promoters and coccidiostat premix* | 1.2 |

| **Nutrient** | **Composition** |
|---|---|
| Dry matter, g/kg | 901.5 |
| Total digestible nutrients (TDN), g/kg | 694.3 |
| Metabolisable energy, MJ/kg | 10.41 |
| Nitrogen free extract, g/kg | 393.6 |
| Crude protein, g/kg | 190.6 |
| Rumen undegradable protein (RUP), g/kg | 43.0 |
| Crude fibre, g/kg | 152.2 |
| Neutral detergent fibre, g/kg | 237.9 |
| Acid detergent fibre, g/kg | 170.2 |
| Ash, g/kg | 102.3 |
| Fat, g/kg | 62.6 |
| Calcium, % | 13.9 |
| Phosphorous, g/kg | 4.3 |

*Premix contains Stafac, Selinomycin and Taurotec.

Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fibre) + (0.9 x nitrogen free extract) + (2.025 x fat).

Calculated Nitrogen free extract =100–(moisture +ash + protein + crude fibre+ fat).

UDP calculated from protein degradability values for maize (63.0%), lucerne meal (68.9%) and cottonseed oilcake (54.5%), at an outflow rate of 0.05 /hr (Erasmus *et al.*,1994).

### 6.2.3 Statistical analysis

Statistical analysis of the data collected was performed using PROC GLM of SAS Enterprise Guide version 7.1 (SAS, 2006). The main effects of sex and breed were compared, as well as the interaction between these effects being tested. Differences between the effects were considered to be significant at the 95% confidence level ($P \leq 0.05$). Average daily gain (ADG) and fat depth gains were calculated as the difference between the final and initial measurements of the feeding period divided by the number of days in the feedlot. Daily feed intake (DMI) was determined by dividing the cumulative intake by the number of days in feed. Feed conversion ratio (FCR) was calculated by dividing the DMI by the ADG. The type III sum of squares was used to analyse the data, with the various traits being expressed as least square means (LSM) with respective standard errors. Differences between effects were evaluated using the Bonferroni test at the 5% significance level, while tendencies were indicated at the $P \leq 0.10$ significance level.

## 6.3 Results

No significant interactions were observed for the majority of the measurements in this study, therefore only the main effects (sex and breed) are presented in tables while interactions are described in text. The feedlot production characteristics of the ewe and ram lambs from the various breeds to obtain the desired A2 carcass fat cover are presented in Table 6.2. As different breeds grow at different rates, the ages of the different production groups varied ($P \leq 0.05$) when introduced to the feedlot at a body weight of 30 kg. Age of ewe lambs (100 days) was older ($P \leq 0.05$) than that of ram lambs (88 days). As pertaining to breed, Namaqua lambs (145 days) were significantly older than the other breeds, followed by Meatmaster (101 days), Merino (91 days), and Dorper (89 days) lambs, compared to the younger Dormer and SAMM lambs (74 and 71 days, respectively). Significant interactions were observed for the number of days in feed, end weight and cumulative feed intake for the various production groups ($P \leq 0.05$). While the length of the feeding period generally did not differ between ewe and ram lambs ($P = 0.574$), interactions were observed as Namaqua ewe lambs were reared for a longer period than Namaqua ram lambs (39 and 18 days, respectively; $P \leq 0.05$). Merino lambs were the longest in feed (43 days), but did not differ significantly from Dohne Merino (39 days), SAMM (37 days) and Dormers lambs, although they were longer in feed than Namaqua (28 days), Dorper (25 days) and Meatmaster lambs (15 days) ($P \leq 0.05$). As with the lengths of the rearing periods, the interaction observed for the end weights of the lambs was also due to Namaqua ewes having a heavier end weight than Namaqua rams (32.9 kg *vs.* 30.6 kg, respectively; $P \leq 0.05$), while the overall end weights of ewe lambs were found to be 9% lighter than that of ram lambs ($P \leq 0.05$). Thus, Namaqua Afrikaner ewe lambs which were reared in the feedlot for a longer period than Namaqua Afrikaner ram lambs also presented heavier end weights than the respective ram lambs, in contrast to the trends shown by the other breeds in this study. South African Mutton Merino, Dohne Merino and Dormer lambs had the heaviest end body weights (~44.4 kg) followed by Merino (42.7 kg), Dorper (39.4 kg) then Meatmaster (35.2 kg) and Namaqua lambs (31.7 kg) ($P \leq 0.05$). The differences and interactions observed with the number of days in feed and end weight also resulted in interactions being observed for cumulative feed intake ($P \leq 0.05$). The interaction was caused by ewe lambs from Dormer and Namaqua breeds having a higher cumulative feed intake than ram lambs, while the general trend showed that cumulative intake of ewe lambs was 13% lower than that of ram lambs. Cumulative intake in Dormer and Namaqua ewe lambs was 51.3 kg and 40.4 kg feed respectively, while that of the respective ram lambs was 46.1 kg and 18.8 kg feed. The lower cumulative intakes of Dormer ram lambs can be ascribed to a lower feed conversion ratio (2.97 kg feed/ weight kg gain), while that of Namaqua ram lambs is as a result of the shorter rearing times. The breeds with the highest cumulative intakes were Merino, Dohne Merino and SAMM (~60.8 kg) followed by Dormer (48.7 kg), Dorper and Namaqua (~30.9 kg); with the lowest cumulative intakes being shown by Meatmaster lambs (19.5 kg; $P \leq 0.05$), as they spent the shortest time in the feedlot.

No interactions between the effects of breed and sex were observed for the production traits ADG, DMI and FCR ($P > 0.05$) (Table 6.2). The growth rate of ewe lambs was on average 24% slower than that of ram lambs ($P \leq 0.05$). The highest ADG was achieved by Dormer lambs (438.6 g/day) which differed significantly from Merino and Namaqua lambs (283.5 and 168.6 g/day, respectively). The growth rates of Dohne Merino (352.3 g/day), Dorper (327.3 g/day), Meatmaster (334.0 g/day) and SAMM (365.0 g/day) lambs did not differ from each other and only differed from that of Namaqua Afrikaner lambs ($P \leq 0.05$). A tendency was observed for the daily intake of ewe lambs to be 6% lower than that of ram lambs ($P = 0.08$), while the DMI of Dohne Merino, Dormer, Merino and SAMM (~1533 g/day) was found to be significantly more than that of Meatmaster and Namaqua lambs (~1150 g/day). The daily intake of Dorper lambs (1245.6 g/day) did not differ from that of any of the other breeds ($P > 0.05$). The feed conversion ratio, defined as the amount of feed required to gain a unit of body weight, was 23% higher for ewe lambs than for ram lambs ($P = 0.003$). The highest unfavourable FCR was obtained by Namaqua lambs (7.08 kg feed/ weight kg gain) which differed ($P \leq 0.05$) from the FCR values obtained by Dohne Merino, Dormer, Dorper, Meatmaster and SAMM lambs, which in turn did not differ from each other (~4.21 kg feed/ weight kg gain). The slightly higher FCR of Merino lambs (5.63 kg feed/ weight kg gain) did not differ from that of the other breeds ($P > 0.05$).

Ultrasound fat depth measurements taken at the 13$^{th}$ rib and between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae (rump) on the *longissimus* muscle are shown in Table 6.3. No interactions between breed and sex were observed for any of the fat depth measurements recorded at the start or end of the feeding period, neither for the rates of fat deposition. As the basis for identifying lambs as slaughter ready was a fat depth of ~5.2 mm, the end fat depths measured at the rump region did not differ (*P* >0.05) with an average fat depth of 5.0 mm.

At the start of the feeding period, ewe lambs had higher fat depths at both the 13$^{th}$ rib (2.9 mm) and rump (3.1 mm) regions than that of ram lambs (2.4mm and 2.8mm, respectively; *P* ≤0.05). The end fat depths at the 13$^{th}$ rib and rump, though, did not differ (*P* >0.05) between the sexes (3.8 mm and 5.1 mm, respectively). Similar trends at both measurement sites were observed for breeds at the start of the trial, with fat depths of Meatmaster lambs (3.1 mm) being thicker than that of Dohne Merino, Dormer, Namaqua lambs (~2.3 mm) at the 13$^{th}$ rib (*P* ≤0.05). At the rump region the initial fat depth of Meatmaster lambs (3.7 mm) differed (*P* ≤0.05) from all the other breeds (~2.7 mm), except the Dorper breed (3.3 mm) which did not differ from the other breeds (*P* >0.05). While the fat depths measured at the rump at the end of rearing periods did not differ (*P* >0.05) between the breeds (Table 6.3), the depths measured at the 13$^{th}$ rib did differ significantly. The highest back-fat depths at this site were recorded by SAMM and Merino lambs (~4.3 mm) which differed (*P* ≤0.05) from that of Namaqua Afrikaner lambs (3.1 mm). The fat depth of the remaining breeds, however, did not differ from any of the other breeds, with an average depth of 3.7 mm measured at the 13$^{th}$ rib.

The fat deposition rate was calculated as the initial fat depth subtracted from final fat depth divided by the length of the feeding period. The fat deposition rate at the 13$^{th}$ rib did not differ between ewes and rams nor between the various breeds (*P* >0.05), with an average fat deposition rate of 0.04 mm/day. At the rump measurement site, no differences in fat deposition rate were observed between ewe and ram lambs (*P* >0.05), however, the rate of fat deposition in Meatmaster (0.12 mm/day) lambs was significantly higher than that of Dohne Merino and Merino lambs (0.06 and 0.05 mm/day, respectively). The fat deposition rates of the remaining breeds did not differ from that of any of the other breeds with an average rate of 0.08 mm/day.

**Table 6.2** Feedlot production characteristics of rearing ewe and ram lambs of seven South African sheep breeds, from an initial body weight of 30.6 kg (27.7 kg for Namaqua lambs) to produce a carcass with ideal fat cover, expressed as least square means ± standard error.

| Main effect | | Age at feed (days) | Days in feed (days) | End weight (kg) | Cumulative intake (kg) | ADG (g/day) | DMI (g/day) | FCR (kg feed/ kg weight gain) |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 100 ± 2.6 | 31 ± 1.4 | 38.5 ± 0.50 | 41.6 ± 2.26 | 279.4 ± 15.29 | 1340.2 ± 37.74 | 5.33 ± 0.269 |
| | Ram | 88 ± 2.5 | 32 ± 1.4 | 42.3 ± 0.49 | 47.6 ± 2.25 | 368.9 ±15.70 | 1425.0 ± 37.45 | 4.32 ± 0.272 |
| | *P-value* | *<0.001* | *0.574* | *,0.001* | *0.043* | *<0.001* | *0.080* | *0.003* |
| Breed | Dohne Merino | $86^{bc}$ ± 4.4 | $39^{ab}$ ± 2.5 | $44.5^{a}$ ± 0.86 | $58.1^{a}$ ± 3.91 | $352.3^{ab}$ ± 26.36 | $1506.6^{a}$ ± 65.29 | $4.61^{b}$ ± 0.457 |
| | Dormer | $74^{c}$ ± 5.4 | $32^{abc}$ ± 3.0 | $44.0^{a}$ ± 1.05 | $48.7^{ab}$ ± 4.79 | $438.6^{a}$ ± 32.28 | $1529.5^{a}$ ± 79.96 | $3.71^{b}$ ± 0.560 |
| | Dorper | $89^{bc}$ ± 4.6 | $26^{c}$ ± 2.6 | $39.4^{b}$ ± 0.90 | $32.1^{bc}$ ± 4.09 | $327.3^{ab}$ ± 27.57 | $1245.6^{ab}$ ± 68.28 | $3.71^{b}$ ± 0.505 |
| | Meatmaster | $101^{b}$ ± 3.5 | $15^{d}$ ± 1.9 | $35.2^{c}$ ± 0.68 | $19.5^{c}$ ± 3.09 | $334.0^{ab}$ ± 21.31 | $1228.2^{b}$ ± 51.61 | $4.57^{b}$ ± 0.369 |
| | Merino | $91^{bc}$ ± 4.9 | $43^{a}$ ± 2.7 | $42.7^{ab}$ ± 0.96 | $67.1^{a}$ ± 4.38 | $283.5^{bc}$ ± 29.47 | $1540.1^{a}$ ± 72.99 | $5.63^{ab}$ ± 0.511 |
| | Namaqua | $145^{a}$ ± 4.6 | $28^{bc}$ ± 2.6 | $31.7^{c}$ ± 0.90 | $29.6^{bc}$ ± 4.09 | $168.6^{c}$ ± 31.26 | $1070.6^{b}$ ± 68.28 | $7.08^{a}$ ± 0.542 |
| | SAMM | $71^{c}$ ± 5.5 | $37^{abc}$ ± 3.1 | $44.8^{a}$ ± 1.07 | $57.1^{a}$ ± 4.89 | $365.0^{ab}$ ± 32.95 | $1554.1^{a}$ ± 81.61 | $4.46^{b}$ ± 0.571 |
| | *P-value* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* |

$^{a-d}$ Column means with different superscripts differ significantly ($P \leq 0.05$).

**Table 6.3** Ultrasound back-fat depth measurements taken at the positions of the 13$^{th}$ rib and between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae (rump), at the start and end of the respective finishing periods of ewe and ram lambs of seven South African sheep breeds, expressed as least square means ± standard error.

| Main effect | | Initial 13$^{th}$ rib (mm) | Initial rump (mm) | End 13$^{th}$ rib (mm) | End rump (mm) | Fat deposition rate 13$^{th}$ rib (mm/day) | Fat deposition rate rump (mm/day) |
|---|---|---|---|---|---|---|---|
| Sex | Ewe | 2.9 ± 0.08 | 3.1 ± 0.09 | 3.9 ± 0.12 | 5.0 ± 0.08 | 0.04 ± 0.007 | 0.07 ± 0.007 |
| | Ram | 2.4 ± 0.08 | 2.8 ± 0.09 | 3.7 ± 0.12 | 5.1 ± 0.08 | 0.05 ± 0.007 | 0.09 ± 0.007 |
| | *P-value* | *<0.001* | *0.020* | *0.219* | *0.184* | *0.341* | *0.106* |
| Breed | Dohne Merino | 2.5$^{b}$ ± 0.15 | 2.7$^{b}$ ± 0.15 | 3.6$^{ab}$ ± 0.21 | 4.8 ± 0.14 | 0.03 ± 0.013 | 0.06$^{b}$ ± 0.012 |
| | Dormer | 2.4$^{b}$ ± 0.18 | 2.8$^{b}$ ± 0.19 | 3.9$^{ab}$ ± 0.25 | 5.1 ± 0.17 | 0.05 ± 0.016 | 0.07$^{ab}$ ± 0.015 |
| | Dorper | 2.8$^{ab}$ ± 0.15 | 3.3$^{ab}$ ± 0.16 | 3.5$^{ab}$ ± 0.22 | 5.1 ± 0.14 | 0.03 ± 0.013 | 0.08$^{ab}$ ± 0.013 |
| | Meatmaster | 3.1$^{a}$ ± 0.12 | 3.7$^{a}$ ± 0.12 | 3.9$^{ab}$ ± 0.16 | 5.3 ± 0.11 | 0.06 ± 0.010 | 0.12$^{a}$ ± 0.010 |
| | Merino | 2.7$^{ab}$ ± 0.16 | 3.0$^{b}$ ± 0.17 | 4.2$^{a}$ ± 0.23 | 4.9 ± 0.15 | 0.04 ± 0.014 | 0.05$^{b}$ ± 0.014 |
| | Namaqua | 2.1$^{b}$ ± 0.15 | 2.6$^{b}$ ± 0.17 | 3.1$^{b}$ ± 0.22 | 5.1 ± 0.14 | 0.04 ± 0.013 | 0.10$^{ab}$ ± 0.013 |
| | SAMM | 2.7$^{ab}$ ± 0.18 | 2.6$^{b}$ ± 0.20 | 4.4$^{a}$ ± 0.26 | 4.9 ± 0.17 | 0.05 ± 0.016 | 0.07$^{ab}$ ± 0.015 |
| | *P-value* | *<0.001* | *<0.001* | *0.005* | *0.206* | *0.463* | *<0.001* |

$^{a-b}$ Column means with different superscripts differ significantly ($P \leq 0.05$).

## 6.4 Discussion

Feedlot finishing, takes advantage of the high growth rates of young animals to rear them from a light body weight with low market value to a heavier body weight which will yield a desirable carcass. This value adding is achieved by feeding concentrated rations to promote muscle growth and fat deposition to enhance the dressing percentage of the carcass as well as improve carcass quality. Feedlot finishing also allows for compensatory growth to occur in lambs that have experienced restricted nutrition, which in turn enhances feeding efficiency of the lambs to a desirable slaughter weight (Shadnoush *et al*., 2011). The goal of lamb feedlot production is to rear the lambs as efficiently as possible to obtain an optimal slaughter weight in as short as time as possible, in order to reduce feeding costs so as to ensure optimal profitability. Alternatively, cheaper feeds with a lower density can be fed for a longer period to obtain the same slaughter weight (Sheridan *et al*., 2003). Early maturing breeds have a shorter rearing period in the feedlot, due to the early onset of fat deposition and so are marketed at lighter slaughter weights to produce a carcass with the same fat cover (Strydom *et al*., 2008). This results in a lower proportion of weight which can be gained in the feedlot (due to the lighter slaughter weight) and so a lower return on investment is achieved.

The main considerations to account for when rearing lambs include differences in growth rate, maturity type and production efficiency. The frame size and mature weight of an animal are often related to maturity and fat deposition, with animals with a lower mature weight and frame size being early maturing (Owens *et al*., 1993). This is evident in particular with ewe lambs that have a lower mature weight than ram lambs (Butterfield, 1988; Van der Merwe *et al*., 2019b) and in the Namaqua Afrikaner and Meatmaster breeds that have small frame sizes. Dorper sheep, however, show exception to this argument as they are early maturing yet they attain relatively higher mature weights (Cloete *et al*., 2000). It has been observed that fat-tailed Damara (a precursor to the Meatmaster) lambs with lighter carcass weights than that of Dorper lambs had similar levels of subcutaneous fat (Tshabalala *et al*., 2003). This suggests that fat-tailed breeds are also early maturing and may even mature earlier than the Dorper, which can be expected as the Dorper is a composite of early maturing Blackhead Persian and later maturing Dorset horn sheep (Milne, 2000). Another consideration related to maturity is the protein deposition rate which increases with the amount of available nutrients until a maximum is reached and then excess nutrients are deposited as fat (Gerrits *et al*., 1996). Siebrits *et al*., (1986) showed that protein deposition in animals was related to the pattern of feed intake, and that lean pigs had higher protein deposition peaks that occurred at a later stage than in obese pigs. This demonstrates that later maturing breeds, which usually have higher mature weights (Owens *et al*., 1993), would exhibit higher growth rates that would peak later than early maturing breeds. The onset of fat deposition occurs at an earlier stage in early maturing breeds, resulting in growth rates peaking at an earlier and at lower levels than that of later maturing breeds. With regards to sheep, these ideas of relating growth rate and mature weight with maturity may be somewhat confounded by wool breeds such as Dohne Merino and Merino ewes that have lower mature weights (Van der Merwe *et al.*, 2019b) and do not exhibit such high levels of fat deposition in relation to the other early maturing breeds. This may be due to partitioning of nutrients to wool production rather than carcass tissue deposition (Adams & Liu, 2003).

As mentioned, the main concepts driving differences between the production groups involve the differences in growth rate as well as maturity type and fat deposition. With regard to the effect of sex, ram lambs grow at a faster rate than ewe lambs while ewe lambs have the propensity to attain maturity at a lighter live weight than intact ram lambs (Butterfield, 1988). Therefore, ewes show higher levels of fat deposition than ram lambs at the same live weight. As shown in Table 6.2, the rearing periods of ewe and ram lambs do not differ while end weights differed due to ram lambs growing faster, while ewe lambs deposit fat at a lighter live weight. Table 6.3 further confirms that ewe lambs have greater fat depths when entering the feedlot while fat deposition occurs at a similar rate in both sexes under an 'ideal' nutrition environment. Johnson *et al.* (2005) confirms this trend by indicating that ewe lambs have greater subcutaneous fat depths than ram lambs when slaughtered at a common body weight. Intact rams also present higher growth rates and are leaner than castrated lambs at slaughter (Schanbacher *et al.*, 1980), while it was shown that the fat depths of ewe lambs and wethers are similar when slaughtered at the same live weight (Dimsoski *et al.*, 1999).

The selection pressures that have historically been applied to each of the breeds used in this study for either wool or meat production, or adaptability, determine the potential performance of the breeds in the feedlot. With an understanding of the performance traits of the respective breeds, specific management strategies in sustainable rearing and marketing of lambs can be implemented. Brand *et al*. (2018) demonstrated that fat deposition in Dorper lambs occurs at higher rates than that observed in SAMM lambs, which was in turn higher than that of Merino lambs. Cloete *et al*. (2012) observed that the subcutaneous fat depths of Dormer and SAMM carcasses were greater than that of Dohne Merino and Merino carcasses. In an earlier study, it was observed that the subcutaneous fat depth of Dormer carcasses was greater than that of SAMM carcasses (Cloete *et al*., 2004). It can thus be assumed that fat-tailed breeds mature earlier than Dorper sheep, followed by the Dormer and SAMM breeds while the Dohne Merino and Merino breeds can be regarded as later maturing. In European sheep breeds, it was seen that the distribution of subcutaneous fat on the carcass remains fairly similar; with higher allometric coefficients for subcutaneous fat deposition being observed around the loin and rib regions and lower coefficients on the neck, shoulder and legs (Kempster, 1981). This study shows that with the exception of the fat-tailed breeds, subcutaneous fat deposition occurs at the same rate in all breeds during this finishing period directly after weaning (0.04 mm/day and 0.07 mm/day at the $13^{th}$ rib and rump, respectively; Table 6.3). The onset of fat accretion is, however, the main factor governing physiological maturity. The fat-tailed breeds show higher rates of fat deposition towards the rump region, specifically, as a result of a major component of fat being stored in the tail-rump region (Negussie *et al*., 2003).

Early maturing breeds, in particular the fat-tailed breeds and Dorper, are thus reared for shorter periods to attain lighter market weights (Table 6.2). High growth rates were attained by Dormer, SAMM, Dohne Merino, Meatmaster and Dorper lambs; with the Dormer lambs demonstrating exceptionally high growth rates in the feedlot. The Dohne Merino, Dormer and SAMM lambs can then also be marketed for slaughter at heavier end weights within 30-40 days of feeding. The feeding efficiency of most of the breeds in the feedlot proved to be favourable, apart from Merino and Namaqua Afrikaner lambs. The Merino breed has a higher predisposition for wool production (Brand & Franck, 2000) rather than meat production and presents a lower growth rate and must so be reared for a longer period, consuming more feed, reducing feed efficiency. While the indigenous Namaqua Afrikaner lambs presented the most unfavourable feedlot production characteristics. The Namaqua Afrikaner is a relatively unimproved breed that has not undergone intensive selection for improved growth and production, but has been adapted for production in extensive arid conditions that other breeds may not be as tolerant towards (Qwabe *et al*., 2013). Due to the early maturing nature of the breed and high level of fat deposition in the tail (Negussie *et al*., 2003), Namaqua Afrikaner sheep would have a greater energy requirement for growth at this body weight range (>30 kg body weight). The energy requirements for fat deposition are greater than that for protein (muscle) deposition due to muscle containing higher quantities of water than adipose tissue (Lawrence *et al*., 2012).

It was observed that DMI in early maturing breeds (Namaqua Afrikaner, Meatmaster and Dorper) tended to be lower than the other breeds. It was hypothesised that this may be due to the smaller frame size of the Meatmaster and Namaqua lambs; though this can also be ascribed to the higher levels of adipose tissue, particularly in the tail, in these early maturing lambs. Leptin hormones are secreted by these adipose tissues, which regulates appetite stimulating or suppression mechanisms and thus intake, depending on the blood leptin concentrations (Pulina *et al*., 2013). It is thus theorised that the breeds that start to deposit fat at an earlier stage may have slightly elevated blood leptin levels compared to the other breeds resulting in a decreased appetite for the high concentrate ration. Further research may be required to prove this hypothesis. The application of different feeding regimes for finishing slaughter lambs, in particular for early maturing breeds, may be necessary. More indigenous breeds, that are reared in extensive conditions, are better utilisers of roughage than improved breeds (Sheridan *et al*., 2003) and so for more cost efficient production lower energy density diets can be used to rear early maturing breeds, while also retarding fat deposition. As the rearing periods of these breeds are shorter, along with lower daily intakes they also have lower cumulative feed intakes, particularly the Meatmaster breed, than the other later maturing breeds. Therefore, these fat-tailed or Dorper breeds can be reared to an ideal slaughter weight, to produce a carcass with the desired level of fat cover, with less feed, however, a smaller carcass would then be obtained at slaughter.

Brand *et al*. (2018) found that finishing periods of 42 days are sufficient to produce the desired carcass from Merino and SAMM lambs and 21 days for Dorper lambs. This coincides well with the findings of the current study. The study by Brand *et al*. (2017) reported higher intakes and feed conversion ratios than that observed for SAMM and Dorper lambs in this study, however the diet used in their study had a lower energy and protein content than that of the current study (9.41 MJ ME/kg feed and 16.0% crude protein *vs*. 10.41 MJ ME/kg feed and 19.1% crude protein, respectively) which accounts for these differences. Terblanche (2013) reported that Dohne Merino rams weaned at 36.5 kg with an ADG of 0.426 kg/day should be reared for 25 days in the feedlot, while ewe lambs weaned at 33.9 kg with a growth rate of 0.289 kg/day should be reared for 45 days. The feedlot production characteristics of Dormer, Meatmaster and Namaqua Afrikaner lambs have not been previously described in literature and this study is the first to highlight the production traits of these breeds.

It is evident from this study that the growth rate and maturity of lambs from different genotypes differ and so different management strategies and rearing times need to be implemented, particularly if feedlotting is deemed an option, to achieve the desired product. With the exception of the Namaqua Afrikaner, the breeds in this study showed acceptable growth rates and feeding efficiencies for commercial feedlot finishing, particularly for the Dormer lambs. The onset of fat deposition does influence the rearing times and marketing weight of lambs from the different breeds. Using ultrasound technology to monitor fat deposition proved to be useful in this study in determining the optimal point of slaughter. Ultrasound technology has previously been used to predict the carcass composition along with subcutaneous fat depth in growing lambs (Hopkins *et al*., 1996), however this is the first study to make use of ultrasound to select animals for slaughter based on subcutaneous fat cover. The implementation of ultrasound technology in lamb rearing may not be feasible with the additional costs of equipment, training and labour. The ultrasound device should also be calibrated with correlations between ultrasound measurements along with carcass measurements in order to make accurate predictions. Before this technology is adopted and implemented in the feedlot industry, the market end weights reported in this study can be used as a guideline for finishing lambs of the various breeds.

## 6.5 Conclusion

From this study, it was seen that in order to produce lamb with the ideal carcass classification, according to South African standards, different rearing strategies are necessary for different sheep breeds. The differences in maturity and the onset of fat deposition account for differences in rearing times in order to produce a carcass with desired expectations. At an average lamb:feed price ratio of 8:1 and feed cost accounting for 75% of feedlot production costs, it will be feasible to finish all of the breeds in this study in a feedlot with the exception of the Namaqua Afrikaner breed. Further research may be necessary to retard fat deposition in these early maturing breeds, as well as the use of less concentrated diets for finishing these breeds in order to reduce feeding costs.

## References


Adams, N.R., Liu, S.M., 2003. Principles of nutrient partitioning for wool, growth and reproduction: implications for nematode parasitism. Aust. J. Exp. Agric., 43, 1399-1407.

Brand, T.S., 2000. Grazing behaviour and diet selection by Dorper sheep. Small Rumin. Res., 36, 147-158.

Brand, T.S., Franck, F., 2000. Production responses of two genetic different types of Merino sheep subjected to different nutritional levels. Small Rumin. Res., 37, 85-91.

Brand, T.S., van der Westhuizen, E.J., van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci. 47, 26- 33.

Brand, T.S., Van Der Westhuizen, E.J., van Der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci., 48, 477-488.

Butterfield, R.M., 1988. New concept of sheep growth. The Department of Veterinary Anatomy, University of Sydney. pp. 1-33.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., Fourie, J.E., 2004. A comparison between the body composition, carcass characteristics and retail cuts of South African Mutton Merino and Dormer sheep. S. Afr. J. Anim. Sci., 34, 44-51.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. Meat Sci., 91, 318-324.

Cloete, S.W.P., Olivier, J.J., 2010. South African Industry. In: Cottle, D.J (ed.). The International Sheep and Wool Handbook. Nottingham University Press, Nottingham. England. pp. 95-112.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V., 2001. Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric., 41, 145-153.

Cloete, S.W.P., Snyman, M.A., Herselman, M.J., 2000. Productive performance of Dorper sheep. Small Rumin. Res., 36, 119-135.

Department of Agriculture, Forestry & Fisheries. 2019. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63. (https://www.daff.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202019.pdf?timestamp=1568549611726 ).

Dimsoski, P., Tosh, J.J., Clay, J.C., Irvin, K.M., 1999. Influence of management system on litter size, lamb growth, and carcass characteristics in sheep. J. Anim. Sci., 77, 1037-1043.

Erasmus, L.J., Botha, P.M., Cruywagen, C.W., Meissner, H.H., 1994. Amino acid profile and intestinal digestibility in dairy cows of rumen-undegradable protein from various feedstuffs. J. Dairy Sci., 77, 541-551.

Gerrits, W.J., Tolman, G.H., Schrama, J.W., Tamminga, S., Bosch, M.W., Verstegen, M.W., 1996. Effect of protein and protein-free energy intake on protein and fat deposition rates in preruminant calves of 80 to 240 kg live weight. J. Anim. Sci., 74, 2129-2139.

Government Notice No. R. 863 of 1 September 2006. Agricultural product standards Act 119 of 1990. Regulations regarding the classification and marketing of meat in the Republic of South Africa.

Hopkins, D.L., Hall, D.G., Luff, A.F., 1996. Lamb carcass. 3. Describing changes in carcasses of growing lambs using real-time ultrasound and the use of these measurements for estimating the yield of saleable meat. Aust. J. Exp. Agric., 36, 37–43.

Houghton, P.L., Turlington, L.M., 1992. Application of ultrasound for feeding and finishing animals: A review. J. Anim. Sci., 70, 930-941.

Johnson, P.L., Purchas, R.W., McEwan, J.C., Blair, H.T., 2005. Carcass composition and meat quality differences between pasture-reared ewe and ram lambs. Meat Sci., 71, 383-391.

Kempster, A.J., 1981. Fat partition and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Sci., 5, 83-98.

Lawrence, T.L.J., Fowler, V.R., Novakofksi J.E., 2012. Growth of farm animals. Second edition. CABI, pp. 216-228.

Milne, C., 2000. The history of the Dorper sheep. Small Rumin. Res., 36, 99-102.

Negussie, E., Rottmann, O.J., Pirchner, F., Rege, J.E.O., 2003. Patterns of growth and partitioning of fat depots in tropical fat-tailed Menz and Horro sheep breeds. Meat Sci., 64, 491-498.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci., 71, 3138-3150.

Peters, F.W., Kotze, A., Van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res., 90, 101-108.

Pulina, G., Avondo, M., Molle, G., Francesconi, A.H.D., Atzori, A.S., Cannas, A., 2013. Models for estimating feed intake in small ruminants. R. Bras. Zootec., 42, 675-690.

Qwabe, S.O., van Marle-Köster, E., Visser, C., 2013. Genetic diversity and population structure of the endangered Namaqua Afrikaner sheep. Trop. Anim. Health Prod., 45, 511-516.

Red Meat Producers Organisation., 2019. (http://www.rpo.co.za/information-centre/absa/weekly-prices/) Accessed 1 September 2019.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Schanbacher, B.D., Crouse, J.D., Ferrell, C.L., 1980. Testosterone influences on growth, performance, carcass characteristics and composition of young market lambs. J. Anim. Sci., 51, 685-691.

Shadnoush, G.R., Alikhani, M., Rahmani, H.R., Edriss, M.A., Kamalzadeh, A., Zahedifar, M., 2011. Effects of restricted feeding and re-feeding in growing lambs: intake, growth and body organs development. J. Anim. Vet. Adv., 10, 280-285.

Sheridan, R., Ferreira, A.V., Hoffman, L.C., 2003. Production efficiency of South African Mutton Merino lambs and Boer goat kids receiving either a low or a high energy feedlot diet. Small Rumin. Res., 50, 75-82.

Siebrits, F.K., Kemm, E.H., Ras, M.N., Barnes, P.M., 1986. Protein deposition in pigs as influenced by sex, type and livemass. 1. The pattern and composition of protein deposition. S. Afr. J. Anim. Sci., 16, 23-27.

Strydom, P.E., Frylinck, L., Van der Westhuizen, J., Burrow, H.M., 2008. Growth performance, feed efficiency and carcass and meat quality of tropically adapted breed types from different farming systems in South Africa. Aust. J. Exp. Agric., 48, 599-607.

Terblanche, T., 2013. An economic analysis of an intensive sheep production system on cultivated pastures in South Africa, incorporating creep feeding and accelerated breeding practices. Mtech. Agric. Thesis Nelson Mandela Metropolitan University, South Africa.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., De Kock, H.L., 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Sci., 65, 563-570.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C. 2019a. Modelling subcutaneous fat deposition in growing South African lambs. Proc. of 65th Int. Con. Meat Sci. Tech., pp. 656-657.

Van der Merwe, D.A., Brand, T.S. & Hoffman, L.C., 2019b. Application of growth models to different sheep breed types in South Africa. Small Rumin. Res., 178, 70-78.

Van Wyk, J.B., Fair, M.D., Cloete, S.W.P., 2003. Revised models and genetic parameter estimates for production and reproduction traits in the Elsenburg Dormer sheep stud. S. Afr. J. Anim. Sci., 33, 213-222.

# Chapter 7 - Slaughter characteristics of premium South African lamb produced from different sheep breed types feedlot-finished


## Abstract

More producers are making use of intensive finishing of their lambs, with the aim of producing a lamb carcass meeting the premium requirements in terms of fat cover and meat quality attributes. In this study, the slaughter characteristics of ram and ewe lambs from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, Namaqua Afrikaner and South African Mutton Merino (SAMM) breeds, reared to an ideal slaughter weight, were determined. Lambs were intensively reared together under feedlot conditions (10.41 MJ ME/kg feed and 19.06% crude protein) from an initial weaning weight of 30 kg until they achieved the desired subcutaneous fat to produce a premium lamb carcass cover (1-4 mm back-fat), when lambs were deemed to be slaughter ready. Subcutaneous back-fat was measured on the *Longissimus lumborum* muscle using an ultrasound scanner at the 13$^{th}$ rib and between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae. After slaughter and chilling, the lamb carcasses were assessed for retail cut yields, carcass composition and physical meat quality. Later maturing lambs attained heavier carcass weights than early maturing breeds (~20.7 kg *vs.* 16.9 kg, respectively; $P \leq 0.05$) and differences in carcass composition and retail cut yields were ascribed to differences in frame size, conformation and pattern of fat deposition of the respective breeds. Small differences in physical meat quality were observed; with meat from Dormer and Namaqua lambs having notably higher shear-force values (~46 N), which still fall within a range that is acceptable to consumers. The redness colour parameter of Namaqua and Dorper (~14.00) samples were higher ($P \leq 0.05$) than that of Dormer and SAMM samples, (~12.62), however, it is doubtful that a consumer would be able to perceive this difference in meat colour. Although the carcass characteristics of the different breeds differ at the given carcass classification, a product with relatively uniform quality can be achieved.


**Keywords:** *Carcass compostion; Subcutaneous fat cover; Maturity; Fat-tailed breeds; Meat quality;*

## 7.1 Introduction

Lamb consumers are generally concerned with the fattiness, tenderness, colour and freshness of the purchased product which is expected to be consistent (Vermeulen *et al.*, 2015). In order to assist the consumer, carcass descriptors have been set by the South African carcass classification system (Government notice No. R. 863, 2006) based on the age, fat cover and conformation of the lamb carcass to provide information on the composition of the carcass as well as expected quality characteristics with fat cover being the main price determinant. Previous studies have shown how subcutaneous fat cover can be used as a predictor for carcass composition, particularly measurements taken on the *longissimus lumborum* muscle between the 3rd and 4th lumbar vertebrae (Bruwer *et al*., 1987a). This specific measurement is used to classify carcasses in terms of tissue composition from no fat (fat score 0) to excessively fat (fat score 6). Prior to the institution of the classification, the industry relied on a grading system which defined the value of carcasses according to carcass standards (Bruwer *et al.,* 1987b; Webb, 2015). The South African market has a high demand for lamb from young sheep (with no permanent incisors, Class A) and a lean fat cover (fat depth of 1- 4mm; Class 2) (Government notice No. R. 863, 2006), with about 72% of sheep slaughtered in registered abattoirs meeting these specifications (Red Meat Producers Organisation, 2019). While not being graded as premium lamb, there is a great demand for carcasses with these classifications (A2) and so a premium price is offered for carcasses that meet these specifications. Unlike the Australian and New Zealand systems which still acknowledges meat from sheep with two permanent incisors, that are not in wear, as lamb (Pannier *et al*., 2019), the South African industry still recognises that yearling (two tooth) lambs do produce carcasses that differ in quality from that of lamb with no permanent incisors (Davel *et al.,* 2003).

In order to obtain a premium value for their carcasses, lamb producers make use of feedlot finishing soon after weaning in order to add value to their lambs in preparation for slaughter. From the viewpoint of a lamb producer, it is important to meet the market demands in order to enhance income from production and sustain optimum profitability. The South African sheep industry is made up of a number of breeds that are developed either for wool (Merino sheep) or meat (Dormer and Dorper breeds) as well as dual-purpose breeds (Dohne Merino and South African Mutton Merino) and fat-tailed sheep breeds (Meatmaster and Namaqua Afrikaner) which are able to survive and produce under more arid conditions. When considering that lambs of different breeds start to deposit fat at different stages as well as exhibit different growth capacities, it is important to implement precision finishing in maintaining production sustainability. Early maturing breeds deposit fat at an earlier stage and must therefore be slaughtered at a lighter live weight compared to later maturing breeds for carcasses to obtain the same classification (Brand *et al*., 2018). With the differences in slaughter weight, it is possible that the different breeds will not only differ in terms of carcass size and shape, but could possibly differ in terms of meat quality characteristics; as it is not clear from previous studies (Bruwer *et al*., 1987a; 1987b) whether the effects of different breeds are accounted for by the quality descriptors.

While the proposed slaughter weights of ~36 kg for Dorper lambs and 42-45 kg for dual-purpose and Merino lambs (Brand *et al*., 2018) have conventionally been used based on slaughter information; in an era of precision farming, technology can be used to give more accurate indications. Ultrasound scanning can be used to measure back-fat cover (Houghton & Turlington, 1992) and so determine the optimal point of slaughter to achieve the desired classification in terms of subcutaneous fat cover.

The aim of this study is to compare the carcass composition and physical meat quality characteristics of ewe and ram lambs from seven different South African sheep breed types, slaughtered at an ideal slaughter weight as determined by back-fat measurements using ultrasound scans to achieve the premium carcass classification (fat class 2; 1-4mm subcutaneous fat measured at the 13$^{th}$ rib and between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae).

## 7.2 Materials and methods

### 7.2.1 Animal management

In this study the carcass and physical meat quality characteristics of ewe and ram lambs from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, Namaqua Afrikaner and South African Mutton Merino (SAMM), slaughtered at an ideal slaughter weight (according to subcutaneous fat cover), were assessed. A total of 150 lambs were slaughtered and carcasses evaluated, with the number of ewe and ram lamb carcasses for the respective breeds being presented in Table 7.1. The rearing and slaughter procedures followed in this study were approved by the Departmental Ethics Committee of Research on Animals (DECRA 14/110) of the Western Cape Department of Agriculture.

**Table 7.1** Numbers of ewe and ram lamb carcasses assessed for the South African sheep breeds slaughtered at an ideal slaughter weight to produce a premium lamb carcass.

| Sheep breed | Ewe | Ram |
|---|---|---|
| Dohne Merino | 19 | 14 |
| Dormer | 8 | 11 |
| Dorper | 11 | 16 |
| Meatmaster | 14 | 16 |
| Merino | 6 | 8 |
| Namaqua Afrikaner | 7 | 6 |
| South African Mutton Merino | 4 | 8 |

The breeds used were obtained from the same resource flock that was flocked together under the same conditions on the Western Cape Department of Agriculture's Langgewens Research farm in the Swartland district of the Western Cape (coordinates: -33.276833, 18.704252) as described in Chapter 6. The ewes were synchronised and bred with rams from the respective breeds, so as to restrict the lambing period to within a month. After lambing, the flock with lambs was kept on cereal stubble with medics pastures (*Medicago truncutula, Medicago, littoralis* and *Medicago polymorpha*). In addition, lambs were allowed *ad libitum* access to creep feed (869.0 g/kg total digestible nutrients, 182. g/kg crude protein, 135.0 g/kg fat, 84.0 g/kg crude fibre, 11.2 g/kg calcium and 7.4 g/kg total phosphorous) before weaning. The tails of Dohne Merino, Dormer, Dorper, Merino and SAMM lambs were docked at two weeks of age, while that of Meatmaster and Namaqua lambs were left intact, as is the commercial practise. The lambs were weighed on a weekly basis, and weaned when they attained a live weight of 30 kg (27 kg for Namaqua Afrikaner lambs), when they were moved to be finished under feedlot conditions. In the feedlot, the lambs were reared on a concentrate feedlot diet (Table 7.2) *ad libitum*. Weekly weighing of the lambs continued with ultrasound (Mindray DP 30V, Shenzhen Mindray Bio-medical Electronics Co., Ltd) scanning of the back-fat depth on the *Longissimus lumborum* muscle at the 13$^{th}$ rib and rump (between the 3$^{rd}$ and 4$^{th}$ lumbar vertebrae).

**Table 7.2** Ingredient formulation and nutritional composition of feedlot diet fed to lambs during study period.

| Ingredient | Inclusion (g/kg As fed) |
|---|---|
| Maize | 500.0 |
| Lucerne hay | 361.0 |
| Cottonseed oilcake | 50.0 |
| Molasses powder | 25.0 |
| Ammonium chloride | 5.0 |
| Ammonium sulphate | 5.0 |
| Lime | 5.0 |
| Monocalcium phosphate | 5.0 |
| Common salt | 10.0 |
| Urea | 5.0 |
| Sodium Bicarbonate | 10.0 |
| Slaked lime | 5.0 |
| Sulphur | 2.0 |
| Vitamin and mineral premix | 1.5 |
| Commercial growth promoters and coccidiostat premix* | 1.2 |

| Nutrient | Composition |
|---|---|
| Dry matter, g/kg | 901.5 |
| Total digestible nutrients (TDN), g/kg | 694.3 |
| Metabolisable energy, MJ/kg | 10.41 |
| Nitrogen free extract, g/kg | 393.6 |
| Crude protein, g/kg | 190.6 |
| Rumen undegradable protein (RUP), g/kg | 43.0 |
| Crude fibre, g/kg | 152.2 |
| Neutral detergent fibre, g/kg | 237.9 |
| Acid detergent fibre, g/kg | 170.2 |
| Ash, g/kg | 102.3 |
| Fat, g/kg | 62.6 |
| Calcium, g/kg | 13.9 |
| Phosphorous, g/kg | 4.3 |

*Premix contains Stafac, Selinomycin and Taurotec.

Calculated total digestible nutrients = (0.8 x protein) + (0.4 x fibre) + (0.9 x nitrogen free extract) + (2.025 x fat).

Calculated Nitrogen free extract =100–(moisture +ash + protein + crude fibre+ fat).

RUP calculated from protein degradability values for maize (63.0%), lucerne meal (68.9%) and cottonseed oilcake (54.5%), at an outflow rate of 0.05 /hr (Erasmus *et al*.,1994;).

### 7.2.2 Carcass characteristics of A2 lamb

The weekly scanning of back-fat depths of lambs was used in order to identify when the lambs were suitable for slaughter to obtain a carcass fat classification of 2 (~4 mm back-fat) (Government notice No. R. 863, 2006). Correction calibrations using the formula: $US = 0.392F + 0.3631$, $R^2 = 0.726$ (where US is the ultrasound measurement and F is carcass fat depth, in cm) (Van der Merwe *et al*., 2019a) was used to predict carcass fat thickness from ultrasound scan measurements. From the above function, the desired 4 mm carcass back-fat threshold equated to an ultrasound measurement of 0.52 cm. As lambs had to be identified for slaughter a week in advance, the threshold ultrasound back-fat measurement of 0.45 cm was used to identify lambs ready for slaughter. After identifying lambs for slaughter, they were kept in a feedlot for five days and on the 6$^{th}$ day the lambs were weighed, scanned and transported to a nearby (~40km) registered commercial abattoir; these measurements were taken as the slaughter weights and final ultrasound scanned fat depths of the lambs. At the abattoir the lambs were held in lairage overnight for ~18hrs before slaughter, with free access to water.

The lambs were slaughtered according to South African standard operating procedures. Electrical stunning was used to render the lambs unconscious (200 V for 5 s), before they were immediately exsanguinated and the carcasses were suspended to assist bleeding out. No electrical stimulation was applied to the lambs at any point in the slaughter line. After bleeding out, the offal components (head, trotters, testes, skins, gastrointestinal tract, red offal as well as abdominal fat) were removed. The warm carcass, containing kidneys and kidney fat, was then inspected and classed by a certified red meat classifier. Carcass classification was performed visually according to the description of Government Notice No. R. 863 (2006). The pH and temperature of the left *longissimus* muscle was measured at the 13$^{th}$ rib 30 minutes post-mortem using a handheld pH meter (ACCSEN PH5 Food). To prevent rapid chilling, carcasses were gradually cooled in a cooling passage for 1-2 hrs post slaughter before chilling at 2 °C for 24 hrs.

After 24 hrs the lambs were transported at 4°C to the laboratory. Upon arrival, the pH and temperature of the cold carcasses were once again measured as described. The cold carcasses were then weighed and a block test was performed, dividing the carcasses into primal retail cuts. Cold carcass weight was expressed as a proportion of the slaughter weight to determine the dressing out percentage of the carcass. The kidneys and kidney fat were removed from the carcass prior to butchery. The different cuts were made as described by Brand *et al*. (2019). The primal cuts consisted of the neck, shoulders, ribs, loin, flanks, legs and tails. The knee sections were sawn off 2.5 cm above the tip of the joint, from both the shoulders and legs, and were regarded as the hocks. Trimmings consisted of non-aesthetic bloodied tissue and sections contaminated with gastrointestinal contents. The components were then weighed separately and expressed as a proportion yield of carcass weight. The block tests were carried out by the same butcher using a knife to limit wastage; a handsaw was only used to remove the hocks. No trimming of excessive carcass fat was performed during the butchery of the lamb carcasses.

A three-rib cut was made between the 9th and 12th ribs on the left side of the animal, to include the 9th, 10th and 11th ribs (Brand *et al.*, 2019). This cut extended from the spinal column up until the plane where the curvature of the ribs moves inward. This three-rib cut was weighed and dissected into bone, lean and fat tissue which were weighed separately and expressed as a proportion of the cut, so as to give an indication of carcass composition.

The left *Longissimus lumborum* muscle was excised from the loin cut and was used for physical quality measurements. The subcutaneous fat depth, and muscle depth was measured at the positions of the 13th rib and between the 3rd and 4th vertebrae using an electronic calliper. The fat and excess connective tissue was then trimmed from the muscle, and three 2.5 cm chops were cut from the muscle and allowed to bloom at 14 °C for 45 minutes. Surface colour measurements of the chops were taken using a digital calibrated handheld Color-guide 45°/0° colorimeter (aperture size 11 mm; illuminate/observer of D65/10°) (BYK-Gardner GmbH, Gerestried, Germany). Calibration of the colorimeter was done using the standards provided (BYK-Gardner) according to the manufacturer’s instructions. Three measurements were taken on the bloomed surface to determine the CIE L* (lightness), a* (red-green range) and b* (blue-yellow range) values. The chroma (colour intensity) and hue angle (colour definition) values were calculated from the individual a* and b* values as described by Honikel (1998). Cooking loss was determined by weighing two of the sample chops together which were then inserted into a polyethylene bag. These samples were cooked in the bags, in a hot water bath at 80°C for 60 minutes. The bags were then removed from the water bath, exuded water drained and samples were submerged in cold water to cool at 4 °C for an hour. The samples were then removed from the bags, blotted dry using paper towels and weighed. The cooking loss was calculated as the difference in weight and expressed as a percentage of original sample weight. The third chop was then used to determine drip loss by weighing the chop and suspending it from a wire in an inflated and sealed polyethylene bag ensuring that the cut did not touch the sides of the bag. The bags were hung in a refrigerator at 4 °C for 24 h. The samples were then removed from the bags and blotted dry using paper towels to remove exudate moisture before weighing. The drip loss was then expressed as the percentage of weight lost over a 24 h period.

Warner-Bratzler shear-force was determined on the cooked meat samples from the cooking loss analysis. For the shear-force analysis, five 2.5 cm cores (1.27 cm in diameter) were cut parallel to the meat fibres from the cooked meat samples. The shear-force of the core samples were determined using an Instron universal testing machine (Instron model 4444/H1028, Apollo Scientific cc, South Africa) fitted with a Warner-Bratzler attachment with a 1 mm thick triangular blade with a semi-circular cutting edge which would cut the core sample perpendicular to the grain. The Instron machine was set to operate with a load cell of 2.000 kN at a speed of 200 mm/min. The shear-force values obtained were then expressed in Newton (N). The shear-force was taken as the average of the five cores analysed for each sample.

### 7.2.3 Statistical analysis

Statistical analysis of the carcass quality data collected was performed using PROC GLM of SAS Enterprise Guide version 7.1 (SAS, 2006). The main effects of sex and breed were compared, as well as the interaction between these effects being tested. Differences between the effects were considered to be significant at the 95% confidence level ($P \leq 0.05$) and tended to differ at the 90% confidence level ($P \leq 0.10$). The calculations of the yields of the various components are described above. The type III sum of squares was used to analyse the data, with the various traits being expressed as least square means (LSM) with respective standard errors. Differences between effects were evaluated using the Bonferroni test at the 5% significance level.

## 7.3 Results

No significant interactions between the main effects of sex and breed for the majority of the carcass and quality characteristics measured were noted and therefore only the main effects are presented in tables with any interactions being described in the text. The slaughter and carcass weights, along with ultrasound measurements prior to slaughter, dressing percentage and average fat class score are presented in Table 7.3. The slaughter ages of the ewes were older than that of ram lambs (130 *vs.* 121 days, respectively; $P = 0.008$). Owing to their slower growth rates, Namaqua Afrikaner lambs were the oldest at slaughter (156 days), followed by Merino lambs (137 days) Dohne Merino lambs (126 days), which all differed from Dormer lambs (110 days) which were the youngest at slaughter ($P \leq 0.05$). The slaughter ages of Dorper, Meatmaster and SAMM lambs (~116 days) did not differ significantly from that of Dohne Merino or Dormer lambs. With regard to slaughter weight, an interaction ($P \leq 0.05$) was observed between the effects of sex and breed which was primarily due to ewe and ram lamb from the Namaqua Afrikaner breed not differing in slaughter weight (32.7 kg and 31.6 kg, respectively), while, ram lambs from the other breeds were heavier than ewe lambs by a factor of ~11% ($P \leq 0.05$) at the same scanned subcutaneous fat depth. A marked difference in slaughter weight between the breeds was observed, with the Dohne Merino, Dormer, Merino and SAMM being heavier at slaughter (~43.1 kg) and Namaqua Afrikaner lambs being the lightest (32.1 kg), with intermediate weights being observed for Dorper and Meatmaster lambs

(37.9 and 35.1 kg, respectively). Ultrasound fat depth scans of the live lambs did not differ between ewes and rams at either of the scanning sites ($P$ >0.05). This was expected as the fat thickness of 5.2 mm at the rump region (3$^{rd}$ and 4$^{th}$ lumbar vertebrae) was taken as the indication for the lambs being ready for slaughter, no differences were observed for fat depth at this site ($P$ >0.05). However, at the position of the 13$^{th}$ rib, Merino lambs had the thickest fat depth (4.5 mm) which differed from that of Dohne Merino (3.7 mm) and Namaqua Afrikaner lambs (3.2 mm) ($P$ =0.002). The scanned fat depths of the remaining breeds did not differ significantly from any of the other breeds. The cold carcass weights followed similar trends to that of slaughter weight, including the interaction of Namaqua Afrikaner ewe and ram lambs not differing in carcass weight (16.0 and 14.2 kg, respectively; $P$ >0.05). Aside from the trends observed for Namaqua lambs, generally carcass weights of ram lambs were on average 7% heavier than that of ewe lambs ($P$ <0.001). South African Mutton Merino lambs presented the heaviest carcasses which differed considerably from Dorper carcass weights, which were in turn heavier than Meatmaster and Namaqua lamb carcasses (22.0 kg, 18.9 kg, 16.6 kg and 15.1 kg, respectively). Carcass weights of Dohne Merino, Dormer and Merino lambs did not differ from that of either SAMM lambs or Dorper lambs ($P$ >0.05). The dressing percentage of ewe lambs was higher than that of ram lambs (49.1% *vs.* 47.2%, respectively; $P$ <0.001). The highest dressing percentage was obtained by the Dorper breed (49.9%) followed by the SAMM (49.8%), Dormer and Merino (48.0%), Meatmaster (47.4%), with the lowest presented by the Dohne Merino and Namaqua breeds (46.9%; $P$ ≤0.05). The fat class score of the different breeds differed ($P$ ≤0.05), even while the animals were selected for slaughter to render a carcass with a fat score of 2. While the average fat score given to the carcasses across breeds was 2, the average score of Meatmaster carcasses (2.6) was higher than that of the other breeds, apart from Namaqua carcasses (2.4), which only differed from that of Dohne Merino carcasses (1.9).

Traits relating to carcass composition were compared in Table 7.4. The fat and muscle tissue depths measured at both the 13$^{th}$ rib and the rump, using a calliper, did not differ between the sexes ($P$ =0.098 and 0.958, respectively), while the depth of these tissues did differ between breeds ($P$ ≤0.05). The fat depth at the 13$^{th}$ rib was thickest for Merino lambs (3.97 mm), differing significantly from that of Dohne Merino (2.54 mm) and Namaqua (2.29 mm) lambs. Similarly, the rump fat of Merino lambs was greater than that of Dormer lambs (7.54 mm *vs.* 5.78 mm, respectively). An interaction ($P$ ≤0.05) was observed for muscle depth at the 13$^{th}$ rib, where the depths of Dormer, Dorper and Namaqua ewes were 8.8%, 8.2% and 26.7% greater than the ram lambs of the respective breeds, while the muscle depth of the sexes of the other breeds did not differ significantly. Muscle depth at the 13$^{th}$ rib of Dormer

**Table 7.3** Slaughter characteristics of ewe and ram lambs of various breeds selected for slaughter at fat scan thickness of 5.2 mm to obtain an A2 carcass, expressed as least square means ± standard error.

| Main effect | | Slaughter age (days) | Slaughter weight (kg) | Fat scan 13$^{th}$ rib (mm) | Fat scan rump (mm) | Cold carcass weight (kg) | Dressing percentage (%) | Fat class* |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 130 ± 2.3 | 37.5 ± 0.48 | 3.9 ± 0.10 | 5.0 ± 0.08 | 18.4 ± 0.24 | 49.1 ± 0.31 | 2.2 ± 0.05 |
| | Ram | 121 ± 1.9 | 41.7 ± 0.43 | 3.8 ± 0.09 | 5.0 ± 0.07 | 19.7 ± 0.22 | 47.2 ± 0.28 | 2.2 ± 0.04 |
| | *P-value* | *0.008* | *<0.001* | *0.625* | *0.510* | *<0.001* | *<0.001* | *0.466* |
| Breed | Dohne Merino | 126$^{bc}$ ± 2.7 | 43.7$^{a}$ ± 0.63 | 3.7$^{bc}$ ± 0.13 | 4.9 ± 0.10 | 20.4$^{ab}$ ± 0.31 | 46.9$^{c}$ ± 0.40 | 1.9$^{c}$ ± 0.07 |
| | Dormer | 110$^{d}$ ± 3.6 | 42.7$^{a}$ ± 0.83 | 4.0$^{abc}$ ± 0.18 | 4.8 ± 0.13 | 20.5$^{ab}$ ± 0.42 | 48.0$^{abc}$ ± 0.53 | 2.1$^{bc}$ ± 0.09 |
| | Dorper | 115$^{cd}$ ± 3.1 | 37.9$^{b}$ ± 0.70 | 4.0$^{abc}$ ± 0.15 | 5.2 ± 0.11 | 18.9$^{b}$ ± 0.35 | 49.9$^{a}$ ± 0.45 | 2.1$^{bc}$ ± 0.07 |
| | Meatmaster | 120$^{cd}$ ± 2.9 | 35.1$^{bc}$ ± 0.67 | 3.7$^{abc}$ ± 0.15 | 5.3 ± 0.11 | 16.6$^{c}$ ± 0.34 | 47.4$^{bc}$ ± 0.43 | 2.6$^{a}$ ± 0.07 |
| | Merino | 137$^{ab}$ ± 4.2 | 41.7$^{a}$ ± 0.96 | 4.5$^{a}$ ± 0.20 | 4.9 ± 0.15 | 20.0$^{ab}$ ± 0.48 | 48.0$^{abc}$ ± 0.62 | 2.2$^{bc}$ ± 0.10 |
| | Namaqua | 156$^{a}$ ± 5.7 | 32.1$^{c}$ ± 0.99 | 3.2$^{c}$ ± 0.21 | 5.1 ± 0.16 | 15.1$^{c}$ ± 0.50 | 46.9$^{c}$ ± 0.64 | 2.4$^{ab}$ ± 0.10 |
| | SAMM | 114$^{cd}$ ± 4.8 | 44.2$^{a}$ ± 1.09 | 3.8$^{abc}$ ± 0.23 | 4.8 ± 0.17 | 22.0$^{a}$ ± 0.55 | 49.8$^{ab}$ ± 0.70 | 2.0$^{bc}$ ± 0.11 |
| | *P-value* | *<0.001* | *<0.001* | *0.002* | *0.078* | *<0.001* | *<0.001* | *<0.001* |

$^{a-d}$ Column means with different superscripts differ significantly ($P \leq 0.05$).

* Average fat classification according to subcutaneous fat depth cover, Class 0 (no fat), Class 1 (<1 mm), Class 2 (1-4 mm), Class 3 (4-7 mm), Class 4 (7-9 mm), Class 5 (9-11 mm) and Class 6 (>11 mm) (Government notice No. R. 863, 2006).

**Table 7.4** Tissue depth and carcass composition characteristics of A2 lamb carcasses of ewe and ram lambs of various breeds, expressed as least square means ± standard error.

| Main effect | | Rib fat depth (mm) | Rump fat depth (mm) | Rib muscle depth (mm) | Rump muscle depth (mm) | Fat tissue (%) | Lean tissue (%) | Bone tissue (%) |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 3.26 ± 0.136 | 6.59 ± 0.209 | 27.04 ± 0.455 | 20.21 ± 0.441 | 37.3± 0.75 | 42.9± 0.58 | 19.4± 0.40 |
| | Ram | 2.96 ± 0.121 | 6.58 ± 0.186 | 26.31 ± 0.405 | 20.01 ± 0.392 | 33.1± 0.67 | 44.8± 0.52 | 21.6± 0.35 |
| | *P-value* | *0.098* | *0.958* | *0.231* | *0.723* | *<0.001* | *0.011* | *<0.001* |
| Breed | Dohne Merino | $2.54^{b}$ ± 0.177 | $6.08^{ab}$ ± 0.271 | $26.72^{b}$ ± 0.592 | $21.71^{a}$ ± 0.573 | $32.6^{bc}$ ± 0.97 | $44.8^{ab}$ ± 0.75 | $22.0^{a}$ ± 0.52 |
| | Dormer | $3.37^{ab}$ ± 0.233 | $5.78^{b}$ ± 0.358 | $31.44^{a}$ ± 0.781 | $21.11^{a}$ ± 0.756 | $37.4^{ab}$ ± 1.28 | $43.9^{abc}$ ± 0.99 | $18.4^{b}$ ± 0.68 |
| | Dorper | $3.11^{ab}$ ± 0.196 | $6.12^{ab}$ ± 0.302 | $29.66^{a}$ ± 0.658 | $18.54^{ab}$ ± 0.637 | $34.3^{bc}$ ± 1.08 | $46.6^{a}$ ± 0.84 | $18.6^{b}$ ± 0.57 |
| | Meatmaster | $3.27^{ab}$ ± 0.189 | $6.86^{ab}$ ± 0.291 | $25.34^{b}$ ± 0.635 | $18.93^{ab}$ ± 0.615 | $39.8^{a}$ ± 1.04 | $40.5^{c}$ ± 0.81 | $19.4^{b}$ ± 0.55 |
| | Merino | $3.97^{a}$ ± 0.271 | $7.54^{a}$ ± 0.416 | $24.50^{bc}$ ± 0.907 | $20.99^{ab}$ ± 0.878 | $37.3^{ab}$ ± 1.49 | $41.5^{bc}$ ± 1.16 | $20.7^{ab}$ ± 0.79 |
| | Namaqua | $2.29^{b}$ ± 0.279 | $6.66^{ab}$ ± 0.429 | $20.82^{c}$ ± 0.935 | $17.40^{b}$ ± 0.905 | $29.2^{c}$ ± 1.53 | $46.6^{a}$ ± 1.19 | $23.6^{a}$ ± 0.82 |
| | SAMM | $3.24^{ab}$ ± 0.307 | $7.07^{ab}$ ± 0.472 | $28.27^{ab}$ ± 1.029 | $22.11^{a}$ ± 0.996 | $35.5^{abc}$ ± 1.69 | $43.0^{abc}$ ± 1.31 | $20.8^{ab}$ ± 0.90 |
| | *P-value* | *<0.001* | *0.011* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* |

$^{a\text{-}c}$ Column means with different superscripts differ significantly (*P* ≤0.05).

and Dorper lambs (~30.55 mm) was greater than that of Dohne Merino and Meatmaster lambs (~26.03 mm), which in turn was greater than the muscle of Namaqua lambs (20.82 mm). The 13$^{th}$ rib muscle depth of SAMM lambs (28.27 mm) only differed from that of Namaqua lambs, while that of Merino lambs (24.50 mm) differed from that of Dormer and Dorper lambs ($P$ ≤0.05). At the rump, the muscle depth of Namaqua lambs (17.40 mm) was significantly thinner than that of Dohne Merino, Dormer, and SAMM lambs (~21.64 mm). At this site, muscle depth of Dorper, Meatmaster and Merino lambs did not differ from the other breeds ($P$ >0.05).

In terms of tissue composition estimated by the three-rib cut (Table 7.4), ewe lambs generally had a greater proportion of fat and lower proportion of lean and bone tissue (37.3%, 42.9% and 19.4%, respectively) than that of ram lambs (33.1%, 44.8% and 21.6%, respectively) ($P$ ≤0.05). Meatmaster lamb carcasses had the highest proportion of fat (39.8%) which differed considerably from that of Dohne Merino and Dorper breeds (~33.5%) and Namaqua lambs (29.2%) ($P$ ≤0.05). Dormer and Merino carcasses also had a greater proportion of fat (37.4%) than Namaqua carcasses ($P$ ≤0.05), while the proportion of fat of SAMM carcasses (35.5%) did not differ from that of the other breeds ($P$ >0.05). With regard to lean muscle tissue, Dorper and Namaqua carcasses presented a greater proportion of lean (46.6%) than Merino (41.5%) and Meatmaster (40.5%) carcasses ($P$ ≤0.05). The proportion of lean muscle in Dormer and SAMM carcasses (~43.5%) did not differ from any of the breeds (P >0.05), while that of Dohne Merino carcasses (44.8%) markedly differed from Meatmaster carcasses. Dohne Merino and Namaqua Afrikaner carcasses consisted of the greatest proportion of bone tissue (~22.8%), while Dormer, Dorper and Meatmaster carcasses had the lowest proportion of bone (~18.8%). The proportion of bone in Merino and SAMM carcasses (~20.8%) did not differ from that of the other breeds ($P$ ≤0.05).

A butchery block test was performed to determine the yields of the primal retail cuts and waste trimmings from a lamb carcass (Table 7.5). Significant interactions between breed and sex were observed for the neck, tail and kidney yields ($P$ ≤0.05). The interaction in neck yields was as a result of the yields of Dohne Merino and Dormer neck cuts not differing between the sexes ($P$ >0.05), while overall with the other breeds, ram carcasses presented larger neck yields than ewes (4.8% *vs*. 4.5%, respectively; $P$ ≤0.05). The interaction in tail yield, was as a result of differences ($P$ ≤0.05) only being observed in breeds with intact tails (Namaqua Afrikaner and Meatmaster), whereas in breeds with docked tails no differences were observed between ewes and rams ($P$ >0.05). As for the interaction in kidney yield, the ewe and ram carcasses from the Merino breed did not differ from each other ($P$ >0.05), whereas the ram carcasses from the other breeds had higher kidney yields than ewe carcasses. Overall, ram lamb carcasses had greater yields of neck, shoulders (16.7% *vs.* 16.2%), tail (1.9% *vs.* 1.6%), hocks (2.1% *vs.* 1.8%) and kidneys (0.7% *vs.* 0.6%) than ewe carcasses ($P$ ≤0.05). Ewe carcasses though presented higher yields of ribs (28.7% *vs.* 28.2%) and flank (6.7% *vs.* 6.2%) cuts than ram carcasses, while the yields of loin and leg cuts, kidney fat and trimmings did not vary significantly between the sexes.

Namaqua Afrikaner lamb carcasses presented the greatest ($P \leq 0.05$) neck yields (5.4%), followed by Merino and Meatmaster carcasses (4.9%), which were in turn greater than that of Dohne, Dormer, Dorper and SAMM carcasses (~4.4%). Shoulder cut yields were greatest in Dohne Merino carcasses (17.4%), which did not differ markedly from that of the SAMM (17.1%) or Merino (16.7%) breeds. On the other hand, Dorper lambs had the lowest shoulder cut yields (15.7%), which did not differ markedly from that of Namaqua (15.8%) or Dormer and Meatmaster carcasses (16.3%). Dormer carcasses presented the highest rib yields (29.4%), which was greater ($P < 0.05$) than Dorper (28.3%), and in turn, Namaqua carcasses (26.2%). The rib yields of Dohne Merino, Meatmaster, Merino and SAMM carcasses did not differ (~28.8%; $P > 0.05$), though were significantly greater than that of Namaqua carcasses. The highest loin cut yields were observed in Dormer, Dorper and Meatmaster carcasses (~6.9%), which were greater ($P \leq 0.05$) than that of Dohne Merino, Merino, Namaqua and SAMM carcasses (~5.7%). Flank cut yields were highest in carcasses from the Meatmaster breed (7.2%) followed by Dorper (6.9%), Dormer and Merino breeds (6.6%), SAMM (6.4%), Dohne Merino (6.2%) and the lowest yields presented by Namaqua Afrikaner carcasses (5.3%; $P \leq 0.05$). The highest yield of leg cuts were presented by Dohne Merino and SAMM carcasses (32.1%), which did not differ ($P > 0.05$) from that of Dormer and Dorper carcasses (31.5%), but did differ from that of Merino (30.9%), Namaqua (30.2%) and Meatmaster (29.8%) carcasses ($P \leq 0.05$). Namaqua Afrikaner lamb carcasses had the greatest tail yields (6.0%) followed by Meatmaster carcasses (2.1%) which were greater ($P \leq 0.05$) than that of breeds with docked tails (~0.8%), which did not differ from each other ($P > 0.05$). No significant differences were observed between breeds for hock yields, though a tendency ($P = 0.053$) was observed for Dohne Merino and SAMM carcasses to have greater yields (~2.1%) and Namaqua carcasses to exhibit lower hock yields (1.8%). Dorper carcasses had the lowest ($P < 0.05$) kidney yields of the breeds (0.5%) which did not differ markedly from that of Dormer and SAMM breeds (0.6%), but did differ from that Dohne Merino, Meatmaster, Merino and Namaqua Afrikaner breeds (0.7%). Kidney fat, with an average yield of 1.9%, did not vary between the different breeds ($P > 0.05$). With regard to trimmings removed during butchery, the greatest yields were removed from SAMM and Merino carcasses (0.5%) compared to the other breeds (0.4%; $P \leq 0.05$).

The pH of the *longissimus* muscle measured 30 minutes post mortem did not differ between the breeds ($P > 0.05$), though the muscle pH of ram lambs (6.84) was higher (P ≤0.05) than that of ewe lambs (6.69) (Table 7.6). An interaction was observed for carcass temperature 30 minutes post mortem ($P = 0.012$), where the temperature of SAMM ram carcasses was higher than ewe carcasses, while overall trends showed ewe carcasses were generally warmer (35.1°C) than that of rams (33.7°C; *P* ≤0.05). A tendency was observed (P =0.086) for the temperature of SAMM carcasses to be warmer than Dohne Merino carcasses when measured 30 minutes post mortem. When pH was measured 24 hours post mortem, no differences were observed between ram and ewe carcasses (*P* >0.05). However, a tendency (*P* =0.051) was observed for Namaqua carcasses to have a higher pH 24 than Dormer, Meatmaster and SAMM carcasses (pH of 5.74, 5.52, 5.56 and 5.54, respectively). The temperature measured 24 hours post mortem also did not differ between sexes (*P* >0.05), while the temperature of Namaqua carcases (6.1 C) was significantly higher than that of Dorper carcases (4.4°C). While cooking loss of muscles from ram carcasses were higher than that of ewes (39.6% *vs*. 38.4%, respectively; *P* ≤0.05), an interaction was observed (*P* =0.024), where the cooking losses of Dohne Merino and SAMM rams did not differ from that of the ewes. Muscles from Dormer carcasses presented higher cooking losses, than that from Merino and Namaqua (40.2 *vs*. 38.3%, respectively; *P* ≤0.05), while cooking losses from the remaining breeds did not differ from each other (*P* >0.05). The effects of sex and breed did not influence (*P* >0.05) drip loss (~1.3%). Sex also did not influence shear-force values (*P* >0.05), while the shear-force of Dormer (46.56 N) and Namaqua (46.09 N) samples was markedly higher than that of Meatmaster (34.89 N). Shear-force values of the remaining breeds did not differ from the other groups (*P* >0.05).

**Table 7.5** Primal retail cut yields (as a proportion of cold carcass weight) of A2 carcasses of ewe and ram lambs of various breeds, expressed as least square means ± standard error.

| Main effect | | Neck (%) | Shoulders (%) | Ribs (%) | Loin (%) | Flanks (%) | Legs (%) | Tail (%) | Hocks (%) | Kidneys (%) | Kidney fat (%) | Trimmings (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 4.5 ± 0.05 | 16.2 ± 0.12 | 28.7 ± 0.15 | 6.3 ± 0.11 | 6.7 ± 0.10 | 31.1 ± 0.15 | 1.6 ± 0.08 | 1.8 ± 0.03 | 0.6 ± 0.01 | 2.0 ± 0.22 | 0.4 ± 0.02 |
| | Ram | 4.8 ± 0.05 | 16.7 ± 0.11 | 28.2 ± 0.13 | 6.2 ± 0.09 | 6.2 ± 0.09 | 31.2 ± 0.13 | 1.9 ± 0.07 | 2.1 ± 0.03 | 0.7 ± 0.01 | 1.7 ± 0.20 | 0.4± 0.02 |
| | *P-value* | *<0.001* | *0.002* | *0.011* | *0.312* | *<0.001* | *0.836* | *0.003* | *<0.001* | *<0.001* | *0.300* | *0.088* |
| Breed | Dohne Merino | 4.4$^{c}$ ± 0.07 | 17.4$^{a}$ ± 0.16 | 28.6$^{ab}$ ± 0.19 | 5.7$^{b}$ ± 0.14 | 6.2$^{c}$ ± 0.13 | 32.1$^{a}$ ± 0.20 | 0.7$^{c}$ ± 0.10 | 2.0 ± 0.04 | 0.7$^{ab}$ ± 0.02 | 1.9 ± 0.29 | 0.4$^{b}$ ± 0.02 |
| | Dormer | 4.3$^{c}$ ± 0.09 | 16.4$^{bcd}$ ± 0.20 | 29.4$^{a}$ ± 0.25 | 6.9$^{a}$ ± 0.18 | 6.6$^{abc}$ ± 0.17 | 31.1$^{abc}$ ± 0.26 | 0.8$^{c}$ ± 0.13 | 1.9 ± 0.05 | 0.6$^{bc}$ ± 0.02 | 1.3± 0.39 | 0.4$^{b}$± 0.03 |
| | Dorper | 4.4$^{c}$ ± 0.08 | 15.7$^{d}$ ± 0.17 | 28.3$^{b}$ ± 0.21 | 7.0$^{a}$ ± 0.15 | 6.9$^{ab}$ ± 0.14 | 31.8$^{ab}$ ± 0.22 | 1.0$^{c}$ ± 0.11 | 1.9 ± 0.04 | 0.5$^{c}$ ± 0.02 | 1.9± 0.33 | 0.4$^{b}$± 0.03 |
| | Meatmaster | 4.8$^{b}$ ± 0.07 | 16.2$^{bcd}$ ± 0.17 | 28.6$^{ab}$ ± 0.20 | 6.7$^{a}$ ± 0.15 | 7.2$^{a}$ ± 0.13 | 29.8$^{d}$ ± 0.21 | 2.1$^{b}$ ± 0.11 | 1.9 ± 0.04 | 0.7$^{ab}$ ± 0.02 | 2.5± 0.31 | 0.4$^{b}$± 0.03 |
| | Merino | 4.9$^{b}$ ± 0.10 | 16.7$^{abc}$ ± 0.24 | 29.0$^{ab}$ ± 0.29 | 5.6$^{b}$ ± 0.21 | 6.6$^{abc}$ ± 0.19 | 30.9$^{bc}$ ± 0.30 | 0.8$^{c}$ ± 0.15 | 1.9 ± 0.06 | 0.7$^{a}$ ± 0.03 | 2.5± 0.45 | 0.5$^{a}$± 0.04 |
| | Namaqua | 5.4$^{a}$ ± 0.11 | 15.8$^{cd}$ ± 0.25 | 26.2$^{c}$ ± 0.30 | 5.8$^{b}$ ± 0.22 | 5.3$^{d}$ ± 0.20 | 30.2$^{cd}$ ± 0.31 | 6.0$^{a}$ ± 0.16 | 1.8 ± 0.06 | 0.7$^{ab}$ ± 0.03 | 1.3± 0.46 | 0.4$^{b}$± 0.04 |
| | SAMM | 4.3$^{c}$ ± 0.12 | 17.1$^{ab}$ ± 0.27 | 28.8$^{ab}$ ± 0.33 | 5.8$^{b}$ ± 0.24 | 6.4$^{bc}$ ± 0.22 | 32.1$^{ab}$ ± 0.34 | 0.7$^{c}$ ± 0.17 | 2.1 ± 0.06 | 0.6$^{bc}$ ± 0.03 | 1.6± 0.51 | 0.5$^{a}$± 0.04 |
| | *P-value* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *0.053* | *<0.001* | *0.156* | *0.036* |

$^{a-d}$ Column means with different superscripts differ significantly ($P \leq 0.05$).

**Table 7.6** Physical meat quality characteristics of *Longissimus lumborum* muscles excised from A2 carcasses of ewe and ram lambs of various breeds, expressed as least square means ± standard error.

| Main effect | | pH 30 | Temperature 30 (°C) | pH 24 | Temperature 24 (°C) | Cook loss (%) | Drip loss (%) | Shear-force (N) |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 6.69 ± 0.046 | 35.1 ± 0.38 | 5.57 ± 0.025 | 5.0 ± 0.19 | 38.4 ± 0.24 | 1.3 ± 0.05 | 41.27 ± 1.28 |
| | Ram | 6.84 ± 0.040 | 33.7 ± 0.34 | 5.64 ± 0.023 | 5.2 ± 0.17 | 39.6 ± 0.21 | 1.2 ± 0.05 | 39.60 ± 1.14 |
| | *P-value* | *0.017* | *0.006* | *0.167* | *0.529* | *<0.001* | *0.206* | *0.645* |
| Breed | Dohne Merino | 6.86 ± 0.060 | 33.1 ± 0.50 | 5.64 ± 0.033 | $5.5^{ab}$ ± 0.24 | $38.6^{ab}$ ± 0.31 | 1.4 ± 0.07 | $38.92^{ab}$ ± 1.66 |
| | Dormer | 6.88 ± 0.079 | 34.8 ± 0.66 | 5.52 ± 0.044 | $4.7^{ab}$ ± 0.32 | $40.2^{a}$ ± 0.40 | 1.3 ± 0.09 | $46.56^{a}$ ± 2.19 |
| | Dorper | 6.65 ± 0.066 | 34.6 ± 0.55 | 5.59 ± 0.037 | $4.4^{b}$ ± 0.27 | $39.8^{ab}$ ± 0.34 | 1.3 ± 0.07 | $39.64^{ab}$ ± 1.85 |
| | Meatmaster | 6.69 ± 0.064 | 35.1 ± 0.53 | 5.56 ± 0.035 | $5.3^{ab}$ ± 0.26 | $39.5^{ab}$ ± 0.33 | 1.4 ± 0.07 | $34.89^{b}$ ± 1.78 |
| | Merino | 6.87 ± 0.091 | 34.0 ± 0.76 | 5.65 ± 0.051 | $5.3^{ab}$ ± 0.37 | $38.3^{b}$ ± 0.47 | 1.4 ± 0.10 | $36.62^{ab}$ ± 2.55 |
| | Namaqua | 6.75 ± 0.094 | 33.8 ± 0.79 | 5.73 ± 0.052 | $6.1^{a}$ ± 0.38 | $38.3^{b}$ ± 0.48 | 1.2 ± 0.11 | $46.09^{a}$ ± 2.62 |
| | SAMM | 6.68 ± 0.103 | 35.3 ± 0.86 | 5.54 ± 0.057 | $4.6^{ab}$ ± 0.42 | $38.6^{ab}$ ± 0.53 | 1.1 ± 0.12 | $40.34^{ab}$ ± 2.89 |
| | *P-value* | *0.102* | *0.086* | *0.051* | *0.004* | *0.002* | *0.206* | *<0.001* |

$^{a-b}$ Column means with different superscripts differ significantly (*P* ≤0.05).

The meat colour attributes of the *Longissimus lumborum* samples from the various lamb breeds are depicted in Table 7.7. The only attribute that was affected by sex was the lightness parameter L*, where ram lambs presented higher L* values than ewes (38.46 *vs.* 37.26, respectively; $P$ <0.001). Samples from Namaqua and Dorper lambs were significantly darker than that of Dormer, Meatmaster and SAMM breeds (36.28 and 36.85 *vs.* ~38.74, respectively). The L* values of Dohne Merino lamb samples (38.12) only differed from that of Namaqua lambs ($P$ ≤0.05), while the lightness of Merino lamb samples did not differ from that of the other breeds ($P$ >0.05). The highest redness values (*a**) were recorded for Namaqua and Dorper samples (~13.99) and the significantly lowest for Dormer and SAMM samples (~12.62). The values of the Dohne Merino, Meatmaster, Merino and SAMM breeds did not differ from any of the breeds ($P$ >0.05). No significant differences were observed between the samples of the different breeds for the yellowness parameter (*b**), with a mean value of 10.50. The hue angle of samples from SAMM lambs (40.96) was markedly higher than that of Dorper and Namaqua lambs (~36.46°), while the values of the other breeds did not differ from any of the other breeds ($P$ >0.05). The chroma values of Namaqua lamb samples were higher than that of SAMM and Dormer samples (17.60, 16.73 and 16.44, respectively; $P$ ≤0.05). The chroma values of Dormer meat samples were also lower ($P$ <0.05) than that of Dorper and Meatmaster breeds (~17.32) which in turn did not differ markedly from the other breeds.

**Table 7.7** Meat colour characteristics of *longissimus lumborum* muscles excised from A2 carcasses of ewe and ram lambs of various breeds, expressed as least square means ± standard error.

| Main effect | | L* | *a** | *b** | Hue (°) | Chroma |
|---|---|---|---|---|---|---|
| Sex | Ewe | 37.26 ± 0.239 | 13.36 ± 0.143 | 10.47 ± 0.144 | 38.18 ± 0.474 | 17.02 ± 0.147 |
| | Ram | 38.46 ± 0.213 | 13.41 ± 0.128 | 10.52 ± 0.128 | 38.12 ± 0.422 | 17.08 ± 0.131 |
| | *P-value* | *<0.001* | *0.796* | *0.804* | *0.916* | *0.743* |
| Breed | Dohne | $38.12^{ab}$ ± 0.311 | $13.47^{ab}$ ± 0.186 | 10.30 ± 0.187 | $37.38^{ab}$ ± 0.617 | $16.97^{abc}$ ± 0.191 |
| | Dormer | $38.54^{a}$ ± 0.410 | $12.64^{b}$ ± 0.247 | 10.46 ± 0.247 | $39.63^{ab}$ ± 0.814 | $16.44^{c}$ ± 0.252 |
| | Dorper | $36.85^{bc}$ ± 0.346 | $13.82^{a}$ ± 0.207 | 10.23 ± 0.208 | $36.54^{b}$ ± 0.686 | $17.23^{ab}$ ± 0.213 |
| | Meatmaster | $38.84^{a}$ ± 0.334 | $13.67^{ab}$ ± 0.200 | 10.74 ± 0.201 | $38.20^{ab}$ ± 0.662 | $17.41^{ab}$ ± 0.205 |
| | Merino | $37.54^{abc}$ ± 0.477 | $13.35^{ab}$ ± 0.285 | 10.44 ± 0.287 | $37.97^{ab}$ ± 0.946 | $16.97^{abc}$ ± 0.293 |
| | Namaqua | $36.28^{c}$ ± 0.491 | $14.15^{a}$ ± 0.294 | 10.39 ± 0.296 | $36.38^{b}$ ± 0.974 | $17.60^{a}$ ± 0.302 |
| | SAMM | $38.85^{a}$ ± 0.541 | $12.59^{b}$ ± 0.324 | 10.95 ± 0.326 | $40.96^{a}$ ± 1.072 | $16.73^{bc}$ ± 0.333 |
| | *P-value* | *<0.001* | *<0.001* | *0.391* | *<0.001* | *0.027* |

$^{a-c}$ Column means with different superscripts differ significantly ($P$ ≤0.05).

## 7.4 Discussion

The South African red meat classification system has set standards to give consumers a description of the quality characteristics that can be associated with the lamb carcass given a specific classification (Bruwer *et al*., 1987b). The system for classing lamb carcasses is based on age (according to dentition) and the subcutaneous fat depth between the 3rd and 4th lumbar vertebrae; though, it does not account for differences between breeds. Breeds developed from indigenous fat-tailed or fat-rump breeds tend to be early maturing and tend to deposit fat at an earlier age as is the case with Dorper, Meatmaster and Namaqua breeds. These breeds also show differences in fat partitioning between the various fat depots as well as the distribution of subcutaneous fat (Negussie *et al*., 2003; Brand *et al*., 2018). Breeds also vary in their growth potential in terms of frame size and growth rate.

As the lambs in this study were reared under optimal growth conditions, they were ready for slaughter at a young age (soon after weaning at 100 days of age). Namaqua Afrikaner lambs, that have a relatively lower mature weight (Qwabe *et al*., 2013) and so exhibit slower growth rates, were only slaughter ready after 150 days of age. As expected, the slaughter weights of early maturing breeds were lighter than the later maturing breeds, to obtain a carcass with the desired fat coverage (Table 7.3). Ewe lambs were slaughtered at lighter body weights than ram lambs, due to ewes maturing earlier than rams and so depositing fat at a lower body weight (Owens *et al*., 1993). In this study, contradicting results were observed with the slaughter weights of Namaqua Afrikaner ewes being slightly heavier, while not differing significantly, than that of ram lambs. Negussie *et al*. (2003) showed that in fat-tailed sheep, fat is primarily deposited in the tail depot, as the name states, before subcutaneous fat is deposited on the rump and the rest of the body. Therefore, the back-fat measurement sites used in this study may not give an apt indication of the level of maturity, in terms of fatness, for this breed with low mature weights which is early maturing but deposits the majority of fat in other depots. Further research may be needed to describe the differences in body fat deposition of Namaqua Afrikaner sheep of different sexes. Overall, the differences in slaughter weight were carried through to the cold carcass weights of the respective breeds even while the dressing percentages of the different breeds varied. During slaughter, the additional weight of the removed testes from rams contributed to the offal component and so resulted in rams having a lower dressing percentage than ewes. Dorper lambs exhibited the highest carcass dressing percentages as a result of higher levels of fat cover throughout the carcass, while Dohne Merino and Namaqua Afrikaner carcasses had leaner ($P$ ≤0.05) fat depths proximal to the 13th rib (Table 7.5). The dressing percentage of a carcass increases with the level of subcutaneous fat cover, and so lambs with a greater distribution of subcutaneous fat will present a higher yield (Brand *et al*., 2018). Tissue composition of the carcasses from the different groups varied. Meatmaster and Namaqua carcasses were given higher average subjective fat scores, due to the presence of the fat tail which might have caught the attention of the classifiers as they viewed the hanging carcasses; even while the back-fat scans at the rump regions did not differ between the breeds prior to slaughter. While the red meat carcass classification system refers to the fat depth at the rump measuring site (Government notice No. R. 863, 2006), which correlates with the carcass tissue composition as described by Bruwer *et al*. (1987a); carcass classifiers consider the carcass as a whole, looking at the fat cover over the ribs and brisket, loin and rump as well as tail regions. Therefore, due to the abundance of fat associated with the tail of the fat-tailed breeds, classifiers do tend to class these carcasses with a higher fat score.

Both measurements from scans prior to slaughter and measurements taken of the muscle after chilling showed that the fat depths differed at the two measurement sites, with the carcasses tending to become leaner as one moves proximal from the rump region. At the same time, the muscle (*Longissimus lumborum*) depths increased as one moved proximal from the rump towards the 13$^{th}$ rib. Cloete *et al*. (2012) also observed that the fat depth measured at the 13$^{th}$ rib was not as thick as that at the rump for Dohne Merino, Merino, Dormer and SAMM sheep. Kempster (1981) showed that the allometric coefficients for subcutaneous fat in European breeds were highest on the rib-loin regions, followed by the breast and chump, with lower coefficients being associated with the leg, shoulder and neck cuts. However, this study shows that greater fat depths are observed nearer to the rump while at the ribs, thinner subcutaneous fat depths were observed. Muscle depths did not exhibit any differences between sexes, the muscle depths of meat type breeds with improved conformation (Dormer, Dorper and SAMM) were greater hinting towards improved musculature of the carcasses. According to the three-rib cut used to estimate tissue composition, carcasses from ram lambs were leaner and had higher proportions of lean and bone tissue than that of ewe lambs. This can again be attributed to the fact that female animals attain maturity earlier than male counterparts and thus are overall fatter when slaughtered at the same stage (Butterfield, 1988; Dimsoski *et al*., 1999). Interestingly, the lighter Namaqua Afrikaner carcasses were the leanest and had the greatest proportions of lean and bone tissue. This is due to the majority of the fat of the breed being deposited in the tail and rump depots, as described by Negussie *et al*. (2003), while fat distribution of the carcass becomes leaner as one moves proximal from the rump. From the three-rib cut, Dorpers also appeared relatively leaner, with a greater muscle yield and more favourable muscle to bone ratio. Dohne Merino carcasses were found to have similar fat and lean muscle yields to that of Dorper, however, they did present a less favourable muscle to bone ratio, as did Merino and SAMM carcasses. Meatmaster carcasses had higher proportions of fat and lower proportions of lean muscle which relates to the lower muscle depths measured in carcasses from this breed. Dormer carcasses were found to have fat and muscle yields resembling the higher levels observed in this study, while also having a lower bone tissue yield. Evaluating the ratio of lean:fat in the saleable meat portion predicted by the three-rib cut, Namaqua carcasses are relatively leaner (1.59:1) followed by Dohne Merino and Dorper carcasses (~1.36:1), SAMM and Dormer carcasses (~1.19:1), while Merino (1.11:1) and Meatmaster (1.02:1) carcasses presented a higher degree of fatness relative to lean meat yield. In terms of carcass conformation, by combining the yields of fat and lean meat tissue and expressing it relative to that of bone, Dormer lambs have the greater conformation (4.4:1) followed by Dorper (4.3:1), Meatmaster (4.1:1), SAMM and Merino (3.8:1), Dohne Merino (3.5:1) and Namaqua lambs with the lowest relative conformation (3.2:1). It should be considered that conformation expressed in this manner is relative to the yields of the carcass tissues from the three-rib cut and does not take the size of the carcass into account, which also contributes to the conformation. Under the South African carcass classification the conformation score is viewed as a descriptor but does not carry importance to the financial value of the carcass as is the case with fat cover and carcass weight as it is argued that conformation will be reflected in the carcass weight; while the yield of the retail cuts determines the overall value of lamb meat production.

Lamb is considered to be a high value red meat commodity with cuts from the leg and loin usually contributing the highest values to the carcass. Aside from the leg and loin cuts, the rib and shoulder cuts are deemed to be higher value cuts, whereas stewing meat associated with the neck, flank and shin are typically regarded as lower value lamb cuts. Due to the popularity of lamb tails as a novelty barbecue snack and for the use of tail-fat in the making of beef and game droëwors (Jones *et al*., 2015), the relative value of this once off-cut has now increased. The traditional butchers block test is used to determine the yields of specific cuts (primal or secondary cuts) and then by incorporating market values to the cuts, profitability of carcass butchery can be determined. Due to the differences in carcass weight and frame size, the relative primal retail cut yields of the carcasses from different breeds with the same fat score differed. The most notable differences are the tail cut yields of the Meatmaster and Namaqua Afrikaner carcasses compared to the other breeds. This is firstly due to the tails of the other breeds being docked within two weeks post-partum, and secondly the enhanced fat deposition in the tail depot. Negussie *et al*. (2003) found that tail fat on average contributes 28.8% of total dissectible fat in fat-tailed breeds. Ewe lambs were also observed to have smaller tails than that of rams; this may possibly be a physiological adaptation of the breeds to assist rams in tail-lifting during mating for improved reproductive success (Kridli *et al*., 2007). Owing to their smaller frame size and lack of conformation, Namaqua Afrikaner carcasses had low rib and shoulder yields. These cuts in Namaqua lambs also have a higher percentage of bone and less meat than Dorper or SAMM carcasses (Burger *et al*., 2013). The lower shoulder yield in Dorper carcasses may be as a result of the shorter wither height of the breed in relation to other breeds of the same frame size. However, leg length was not measured in this study to confirm this. Breeds with better body conformation (SAMM, Dohne Merino, Dormer and Dorper) presented higher leg cut yields due to improved muscling, while Dorper, Dormer and Meatmaster lambs had the highest loin cut yields relative to carcass weight.

While carcass muscle pH after slaughter and after chilling did not differ between the breeds, differences in CIE Lab surface colour parameters were observed. The muscle surface colour of samples from Dormer, Meatmaster and SAMM lambs was lighter and had lower redness (a*) values with generally higher hue angles and lower chroma values. Meat from Namaqua Afrikaner and Dorper lambs was generally darker with greater redness values, lower hue angles and greater chroma saturation values (Table 7.7). With regard to the effect of sex, meat from ram lambs was lighter than that of ewes. Cloete *et al.* (2012) also observed meat from Dormer sheep to be lighter than that of Merino, Dohne Merino and SAMM sheep, while the other colour parameter values did not differ. Khliji *et al*. (2010) found that on average, Australian consumers accepted lamb meat with an L* value of 34 and a* value of 9.5 while 95% of consumers still find lamb meat with an L* = 44 and a* = 14.4 still acceptable. The colour parameter values of meat from lamb breeds in this study were higher than the average threshold values reported by Khliji *et al*. (2010) and so consumers would consider the colour of the lamb meat to be acceptable.

As muscle pH did not differ, drip loss also did not differ between the breeds. Although, meat sampled from Dormers had a significantly higher cooking loss than that of Merino and Namaqua Afrikaner lambs. As a result of the greater cooking loss in Dormer samples, higher shear-force values were also observed. This is partly due to the density of muscle fibres increasing within the cooked meat sample as moisture is lost. Though, Hoffman *et al*., (2003) reported that Warner-Bratzler shear-force of meat from Dormer crossbreed lambs was greater than that of crosses with other breeds, and so suggesting a possible breed effect. Shear-force values from Namaqua lambs resembled that of the Dormers. These shear-force values though do not correlate with tough meat but rather fall into the intermediate category (42.87-52.68 N) while samples from the other breeds can be regarded as tender (32.96-42.77 N) (Destefanis *et al*., 2008).

The role of carcass classification is to set descriptors so that carcasses are classified to ensure more consistent meat quality (Webb, 2015). Consumers desire a meat product that is lean, but still contains sufficient fat to ensure a good eating experience (Webb & O'Neill, 2008). Therefore, the South African market is driven to produce lamb with a carcass fat classification of 2, which also ensures minimal trimming of fatter carcasses and so reducing profitability (Strydom *et al*., 2009). While the aim is to produce a lamb carcass with uniform quality and composition, fat cover does vary across the carcass (Strydom *et al*., 2009) with patterns of fat deposition in carcass and non-carcass depots varying between breeds, particularly in fat-tailed breeds (Negussie *et al*., 2003, Tshabalala *et al*., 2003; Burger *et al*., 2013). The frame size or mature weights of the various breeds differ (Van der Merwe *et al*., 2019b) and so body conformation and musculature will vary resulting in differences in tissue composition as well as the yield of carcass cuts. Under the same rearing conditions, objectively measured differences in physical meat quality characteristics were observed between breeds. However, the range of variability observed for these traits still falls within an acceptable range for consumers. The impact of producing lamb from different breeds would have a greater effect on profitability of meat processors than on end consumers. Certain markets though have preference for lamb carcasses of different sizes, depending on the products they promote. Thus, there is place in the value chain for each of the sheep breed types for lamb production with strategic marketing. Using the results of this study as a guideline, taking into account available resources and implementing specific strategies, sustainable feedlot lamb production can be accomplished, with processors also having to strategize their carcass butchery for optimal profitability.

## 7.5 Conclusion

Differences in maturity and the onset of fat deposition account for the differences in carcass weights for the different breeds. Although the carcass classification system is well suited to describe the carcass of most breeds, it must be considered that with regard to fat-tailed breeds, while proximal to the rump the carcasses are relatively lean, the fat deposition surrounding the tail and rump does influence the decision of the carcass classifiers. The different breeds exhibit different frame sizes and body conformations at the desired degree of carcass fat cover. This influences the yields of specific cuts and degree of lean muscle within the cuts.

Within the same carcass fat class, small differences in physical meat quality characteristics were observed, which may not necessarily be detected by consumers. Even differences relating to instrumental shear-force between the breeds, fall within a range that is still acceptable to consumers. Therefore, slaughtering lambs of different breeds, at the same degree of fatness, results in lambs being reared for different periods, to obtain a carcass that varies in size and conformation; though still presenting similar meat quality characteristics.

## References

Brand, T.S., Van Der Merwe, D.A., Swart, E., Hoffman, L.C., 2019. The effect of finishing period and dietary energy content on the carcass characteristics of Boer goats. Small Rumin. Res., 174, 110-117.

Brand, T.S., Van Der Westhuizen, E.J., van Der Merwe, D.A., Hoffman, L.C., 2018. Analysis of carcass characteristics and fat deposition of Merino, South African Mutton Merino and Dorper lambs housed in a feedlot. S. Afr. J. Anim. Sci., 48, 477-488.

Bruwer, G.G., Naude, R.T., Du Toit, M.M., Cloete, A., Vosloo, W.A., 1987a. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 2. The use of fat measurements as predictors of carcase composition. S. Afr. J. Anim. Sci., 17, 85-89.

Bruwer, G.G., Naude, R.T., Vosloo, W.A., 1987b. An evaluation of the lamb and mutton carcase grading system in the Republic of South Africa. 1. A survey of carcase characteristics of the different grades. S. Afr. J. Anim. Sci., 17, 79-84.

Burger, A., Hoffman, L.C., Cloete, J.J.E., Muller, M., Cloete, S.W.P., 2013. Carcass composition of Namaqua Afrikaner, Dorper and SA Mutton Merino ram lambs reared under extensive conditions. S. Afr. J. Anim. Sci., 43, S27-S32.

Butterfield, R.M., 1988. New concept of sheep growth. The Department of Veterinary Anatomy, University of Sydney.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. Meat Sci., 91, 318-324.

Davel, M., Bosman, M.J.C., Webb, E.C., 2003. Effect of electrical stimulation of carcasses from Dorper sheep with two permanent incisors on the consumer acceptance of mutton. S. Afr. J. Anim. Sci., 33, 206-212.

Destefanis, G., Brugiapaglia, A., Barge, M.T., Dal Molin, E., 2008. Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. Meat Sci., 78, 153-156.

Dimsoski, P., Tosh, J.J., Clay, J.C., Irvin, K.M., 1999. Influence of management system on litter size, lamb growth, and carcass characteristics in sheep. J. Anim. Sci., 77, 1037-1043.

Erasmus, L.J., Botha, P.M., Cruywagen, C.W., Meissner, H.H., 1994. Amino acid profile and intestinal digestibility in dairy cows of rumen-undegradable protein from various feedstuffs. J. Dairy Sci., 77, 541-551.

Government Notice No. R. 863 of 1 September 2006. Agricultural product standards Act 119 of 1990. Regulations regarding the classification and marketing of meat in the Republic of South Africa.

Hoffman, L.C., Muller, M., Cloete, S.W.P., Schmidt, D., 2003. Comparison of six crossbred lamb types: sensory, physical and nutritional meat quality characteristics. Meat Sci., 65, 1265-1274.

Honikel, K.O., 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci., 49, 447-457.

Houghton, P.L., Turlington, L.M., 1992. Application of ultrasound for feeding and finishing animals: A review. J. Anim. Sci., 70: 930-941.

Jones, M., Hoffman, L.C., Muller, M., 2015. Oxidative stability of blesbok, springbok and fallow deer droëwors with added rooibos extract. S. Afr. J. Sci., 111, 1-8.

Kempster, A.J., 1981. Fat partition and distribution in the carcasses of cattle, sheep and pigs: a review. Meat Sci., 5, 83-98.

Khliji, S., Van de Ven, R., Lamb, T.A., Lanza, M., Hopkins, D.L., 2010. Relationship between consumer ranking of lamb colour and objective measures of colour. Meat Sci., 85, 224-229.

Kridli, R.T., Shaker, M.M., Abdullah, A.Y., Muwalla, M.M., 2007. Sexual behaviour of yearling Awassi, Charollais× Awassi and Romanov× Awassi rams exposed to oestrous Awassi ewes. Trop. Anim. Health Prod., 39, 229-235.

Negussie, E., Rottmann, O.J., Pirchner, F., Rege, J.E.O., 2003. Patterns of growth and partitioning of fat depots in tropical fat-tailed Menz and Horro sheep breeds. Meat Sci., 64, 491-498.

Owens, F.N., Dubeski, P., Hanson, C.F., 1993. Factors that alter the growth and development of ruminants. J. Anim. Sci., 71, 3138-3150.

Pannier, L., Gardner, G.E., Pethick, D.W., 2019. Effect of Merino sheep age on consumer sensory scores, carcass and instrumental meat quality measurements. Animal Production Science, 59, 1349-1359.

Qwabe, S.O., van Marle-Köster, E., Visser, C., 2013. Genetic diversity and population structure of the endangered Namaqua Afrikaner sheep. Trop. Anim. Health Prod., 45, 511-516.

Red Meat Producers Organisation., 2019. (http://www.rpo.co.za/information-centre/absa/weekly-prices/) Accessed 1 September 2019.

SAS Institute, 2006. SAS/Stat User's Guide Version 9, 1st printing, Volume 3, SAS Institute, Inc, SAS Campus Drive, Cary, North Carolina 27513.

Strydom, P.E., Van Heerden, S.M., Van Heerden, H.C., Kruger, R., Smith, M.F., 2009. The influence of fat score and fat trimming on primal cut composition of South African lamb. S. Afr. J. Anim. Sci., 39, 233-242.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., De Kock, H.L., 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Sci., 65, 563-570.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C. 2019a. Modelling subcutaneous fat deposition in growing South African lambs. Proc. of 65th Proc. of 65th Int. Con. Meat Sci. Tech., pp. 656-657.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019b. Application of growth models to different sheep breed types in South Africa. Small Rumin. Res., 178, 70-78.

Vermeulen, H., Schönfeldt, H.C., Pretorius, B., 2015. A consumer perspective of the South African red meat classification system. S. Afr. J. Anim. Sci., 45, 339-354.

Webb, E.C., 2015. Description of carcass classification goals and the current situation in South Africa. S. Afr. J. Anim. Sci., 45, 229-233.

Webb, E.C., O'neill, H.A., 2008. The animal fat paradox and meat quality. Meat Sci., 80, 28-36.

# Chapter 8 - Description of wool production in Dohne Merino, Dormer, Merino and South African Mutton Merino lambs


## Abstract

As interest in wool production regains popularity, it is important to be able to predict wool production of lambs from major wool breeds. In this study, wool growth of Dohne Merino, Dormer, Merino and South African Mutton Merino (SAMM) lambs reared on a feedlot diet (10.62 MJ ME/ kg feed, 159 g/kg crude protein) was monitored using the midrib patch measurement technique, from about two months of age until the lambs were shorn as yearlings. The 10 by 10 $cm^2$ patches on the left sides of the lambs were shorn on a monthly basis and the clippings weighed in order to determine wool growth rate. At approximately one year of age, the lambs were shorn and the fleeces weighed. A mid-rib fleece sample was also retrieved from each individual for quality analysis. The fleece weights (12 months), as well as wool quality characteristics, of the dams of the lambs from the respective breeds were also included in the study. Merino lambs presented the highest wool growth rates (12.943 g/day) and fleece weights (6.140 kg), while Dormer lambs exhibited the lowest values for these traits (8.487 g/day and 3.330 kg, respectively; $P \leq 0.05$). The lack of differences observed between Dohne Merino (9.720 g/day and 4.671 kg) and SAMM (10.553 g/day and 4.158 kg) lambs for these wool growth rate and fleece weight traits were attributed to the differences in live weight (86.8 kg and 105.2 kg, respectively; $P \leq 0.05$), with heavier SAMM lambs offsetting expected differences in fleece weight. Wool from Dohne Merino and Merino sheep had the finest fibre diameters (<21 μm) followed by SAMM wool (22-23 μm) with Dormers producing coarse wool (>27 μm). These results can be used as a guideline in sheep production in predicting the income contribution from wool for the various breeds.


**Keywords:** *Wool growth rate; Fleece weight; Fibre diameter; Predictions*

## 8.1 Introduction

Sheep wool continues to be an important fibre in textile production. The economic value of wool is influenced by intrinsic characteristics that meet processor capacities and consumer requirements (Holman & Malau-Aduli, 2012). The quantities of wool produced annually in the South African market, experienced a decline from 1991 to 2005 (DAFF, 2018) as a result of increased stock theft, as well as the meat price becoming more favourable in being the major source of income from sheep production. This resulted in increased crossbreeding programs, with terminal sires, so as to improve growth and meat production of wool breeds being implemented (Cloete *et al*., 2008). Wool production though, does complement to lamb production for the total income generated when wool type or dual-purpose dam lines are used in breeding programs (Cloete, 2007). Wool production in South Africa, though, has since grown as a result of higher wool market prices, with 51600 tonnes of wool being produced in 2016/2017, drawing a revenue of ZAR 4.2 billion (DAFF, 2018). The increased demand for South African wool by processors, was in part also driven by the boycott on the Australian wool industry which still practiced mulesing as a method to control flystrike, which consumers viewed as a welfare violation of the sheep (Sneddon & Rollin, 2010).

The South African sheep industry consists of a diverse range of breeds and production types, which are suited to different production systems. Wool type breeds make up about 72% of the national flock (DAFF, 2018). According to weaning weight records of the National Small Stock Improvement Scheme, 49.7% of the dataset is made up of Merino and Dohne Merino breeds; with South African Mutton Merino (SAMM) contributing 18.1% and Dormer breeds 7.1%, followed by Il de France (2%) and Merino landsheep as well as Afrino breeds which contribute less than 2% (Cloete *et al*., 2014). The Letelle breed, a descendant of the Spanish Merino, contributes a small portion of the national flock with ~3000 registered ewes and ~100 registered rams (Van der Westhuizen *et al*., 2019). The remainder of the national flock is made up of breeds that are explicitly reared for meat production.

Currently, the lamb meat prices continue to be favourable, even while income derived from wool has increased considerably over the past few years. As a result, many lamb producers opt to intensively rear their lambs in intensive feedlot systems in order to improve production efficiency and maximise throughput. Feedlot lambs typically enter the feedlot at weaning (3-4 months of age) and are marketed for slaughter at ages of 4-6 months (Brand *et al*., 2017); while in other extensive production systems, lambs are reared up to yearling age. In these production systems, the lambs are shorn at either 8 months of age or at year old so as to obtain a suitable fleece. In large commercial feedlots, there is an option of shearing lambs in order to enhance the income per lamb. It is also suggested that shearing lambs directly prior to entry in the feedlot will increase feed intake by stimulating cold stress (Çam *et al*., 2007) and so enhance production. Conversely, it is also suggested that the additional protein and energy in the feedlot diet will result in greater wool growth (Cronje & Weites, 1990) and so result in a heavier fleece at the end of the feeding period prior to slaughter. To produce a quality wool sheepskin, tanneries require a staple length of 25-50 mm, but not exceeding 50 mm which results in the undesirable felting of the wool pile (Holst *et al*., 1996). These wool staple lengths should be taken into consideration for the marketing of sheep skins, and the time of shearing and slaughter then planned accordingly. Regardless of the production system, and age of shearing of wool type lambs in the system, it is important to be able to predict wool production of the lambs so as to determine the expected income and feasibility of the management strategy. Previous genetic studies have described wool production characteristics as well as associated genetic variances of these traits for Merino, Dohne Merino and SAMM lambs that were sheared at about 12 months of age (Cloete *et al.,* 1998; Snyman *et al*., 1998; Cloete *et al*., 2001; Cloete *et al*., 2004). The wool growth rates of growing lambs of these breeds have also been described by Du Plessis & De Wet (1981). While no information in literature could be found describing the wool production of Dormer lambs. Although these studies give an indication of the wool production of the various breeds, it is still important to be able to make predictions of wool growth and fleece weight of growing lambs up to yearling age.

The aim of this study was to describe the wool growth rates of growing lambs and to model wool growth with age and body weight for Dohne Merino, Dormer, Merino and SAMM lambs. In addition to this, to also to describe the wool quality traits of yearling lambs, of the respective breeds, reared on a feedlot diet for optimum growth; as well as describe the wool production of dams of the various breeds reared under the same conditions.

## 8.2 Materials and methods

### 8.2.1 Animal management

Ethical approval for this study was obtained from the Western Cape Department of Agriculture's departmental ethics committee (DECRA R14/110). In this study, the wool production characteristics of lambs from four breeds, namely, Dohne Merino (ram = 5, ewe = 14), Dormer (ram = 9, ewe = 10), Merino (ram = 3, ewe = 2) and South African Mutton Merino (SAMM) (ram = 13, ewe = 7) sheep were monitored from about 30 days of age until they attained mature body weights (~1 year of age). The research flock containing 25 ewes per breed of the respective breeds was herded on Langgewens Research farm (Western Cape Department of Agriculture) in the Swartland region of the Western Cape in South Africa (coordinates: -33.276833, 18.704252). A description of the management and nutrition of the flock as well as post-weaning feedlot nutrition of the lambs is outlined by Van der Merwe *et al*. (2019). From weaning, the lambs were reared on a feedlot diet (primarily containing maize, *Medicago sativa* hay and cotton seed oilcake) that was formulated for optimal growth, containing 708 g/kg total digestible nutrients, with a crude protein content of 159 g/kg, 10.62 MJ/kg metabolisable energy, 219 g/kg neutral detergent fibre, 26 g/kg calcium and 8.0 g/kg phosphorous. The high concentrate diets supplied to lambs were fed in order for lambs to attain optimal growth according to the potential of the breed. Throughout the study period, the different breeds were herded together. The ewes of the various breeds were synchronised and mated with rams from the respective breeds, with lambing occurring within a month during the period May- June 2017. Unfortunately, due to low lambing rates, particularly in the Merino breed, the number of lambs available for this study was lower than anticipated. Nonetheless, analysis was still carried out in order to determine wool production of the growing lambs at a given age or live weight.

### 8.2.2 Wool measurements

Wool growth rate was monitored using the mid-rib patch technique (Langlands & Wheeler, 1968). A 10 cm by 10 cm patch was demarcated using ink on the skin on the left side of the lambs in the centre of the mid-rib region. At this time, the lambs in this study were about two months of age, when the wool within this patch was cleared for the first time using an electric clipper (Andis Ultra Edge) with a 1.5 mm blade. Following this initial clipping, the wool within the demarcated patches was clipped, consecutively, on a monthly basis. The wool clipped from each patch was then weighed (greasy weight) using an electronic scale and corrected according to the 100 cm$^2$ surface area of the size of the original patch. In order to determine fleece growth between monthly clipping intervals, the following formula proposed by Ferguson (1958) was applied:

$$Total\ wool\ production = 6\ \times\ W^{\frac{2}{3}}\ \times wool\ mass\ from\ 100\ cm^2\ area$$

This formula was used to determine wool growth in Dohne Merino, Dormer and SAMM lambs. While, as Merino lambs have more skin folds, and thus have a greater surface area, the following formula was used to determine wool production of Merino lambs (Du Plessis, 1974):

$$Total\ wool\ production = 6.5\ \times\ W^{\frac{2}{3}}\ \times wool\ mass\ from\ 100\ cm^2\ area$$

In both formulas, *W* denotes the weight (kg) of the lambs at the time of clipping. At about 12 months of age (May 2018), the patches were clipped a final time and the fleeces of the lambs were shorn. The entire fleece of each animal was weighed on a platform scale in order to obtain the greasy fleece weight. A mid-rib wool sample (~75 g) was also taken from the right side of the animals to determine wool quality characteristics. The dams of the respective breeds were shorn during the spring months (September-October 2018), in order to obtain a year old fleece from producing mature ewes. The fleeces were weighed and samples extracted from the fleece in the same way as described above. The collected wool samples were sent to the Wool Testing Bureau (Port Elizabeth, South Africa) in order to determine clean yield as well as fibre length, fibre diameter and crimp frequency characteristics.

### 8.2.3 Statistical analysis

The data collected in this study was analysed using SAS Enterprise Guide (SAS version 7.1). Wool growth per unit area (mg/cm$^2$/day), monthly fleece growth (g) (calculated using the above formulas using the weights of the patch clippings and body weights), and wool growth rates (g/day) were averaged across the monthly clippings for each animal to determine average wool growth rates during the study period. Using the PROC GLM function of SAS, wool growth rates and quality characteristics were analysed for differences with the main effects of breed and sex, as well as for breed by sex interactions using type three sums of squares. For the wool characteristics of the mature ewes, only the main effect of breed was included in the analysis, as only wool from ewes was used. The Bonferroni test method was used to determine significant differences between the main effects at the 95% level ($P \leq 0.05$) while tendencies were observed at the 90% confidence level ($P \leq 0.10$). Monthly fleece growth values were deducted from the fleece weight at shearing (~ 1 year of age) in order to estimate the cumulative fleece weight at the points of patch clipping. Linear regressions to model the change in greasy fleece weight and clean fleece weight with age or body weight were developed for each individual using PROC REG (SAS version 7.1). The linear parameter estimators were then compared for differences with the main effects of breed and sex. The results are presented as least square means along with accompanying standard errors.

## 8.3 Results

With respect to the wool growth and quality traits as well as value parameter estimators, no significant interactions were observed between the effects of breed and sex. At the start of the study, Dormer lambs were older (66 days) than Dohne Merino and SAMM lambs (~57 days) which were in turn older than Merino lambs (43 days) ($P < 0.001$). However, the body weights of the lambs did not differ ($P = 0.122$) at the start of the wool growth monitoring period (Table 8.1). As the ages of the lambs at the start of the trial differed, the ages of the lambs at the point of shearing differed in the same manner ($P < 0.001$). The average age of the lambs at shearing was ~349 days, which was taken as an indication of one-year old fleece weight. At shearing, Dormer and SAMM sheep were significantly heavier than the Dohne Merino and Merino breeds (105.3 kg and 105.2 kg *vs*. 86.8 kg and 82.6 kg, respectively) also, rams were on average 18.3% heavier than ewes ($P < 0.001$). As the ages at shearing differed, the fleece weight was corrected to 365 days of age to represent one-year old fleece weight. The greasy fleece weight of rams was 14.4% heavier than that of ewes ($P \leq 0.05$), which was primarily due to the rams being larger than the ewes of the respective breeds. Merino lambs produced the heaviest fleeces (6.140 kg), while fleece weights of Dohne Merino and SAMM lambs did not differ significantly from each other (~4.415 kg) and Dormers producing the lightest fleece (3.330 kg) ($P < 0.001$).

**Table 8.1** Least square means (± S.E.) of age and body weight of lambs at the start of wool growth study (~2 months of age) and at final shearing (~1 year of age) with greasy fleece weight of ram and ewe lambs of different breeds.

| Main effect | | Start age (days) | Start body weight (kg) | Shearing age (days) | Shearing body weight (kg) | Greasy fleece weight (kg) |
|---|---|---|---|---|---|---|
| Sex | Ewe | 57 ± 1.6 | 16.7 ± 1.15 | 347 ± 1.7 | 85.4 ± 2.29 | 4.220 ± 0.1812 |
| | Ram | 55 ± 1.5 | 16.9 ± 1.15 | 345 ± 1.5 | 104.5± 2.12 | 4.930 ± 0.1671 |
| | *P-value* | *0.488* | *0.911* | *0.646* | *<0.001* | *0.006* |
| | | | | | | |
| Breed | Merino | $43^{c}$ ± 3.2 | 14.8 ± 2.16 | $333^{c}$ ± 3.3 | $82.6^{b}$ ± 4.61 | $6.140^{a}$ ± 0.3641 |
| | Dohne Merino | $57^{b}$ ± 1.7 | 16.0 ± 1.15 | $347^{b}$ ± 1.8 | $86.8^{b}$ ± 2.46 | $4.671^{b}$ ± 0.1946 |
| | SAMM | $58^{b}$ ± 1.7 | 17.1 ± 1.11 | $348^{b}$ ± 1.7 | $105.2^{a}$ ± 2.37 | $4.158^{b}$ ± 0.1870 |
| | Dormer | $66^{a}$ ± 1.6 | 19.3 ± 1.08 | $357^{a}$ ± 1.8 | $105.3^{a}$ ± 2.45 | $3.330^{c}$ ± 0.1938 |
| | *P-value* | *<0.001* | *0.122* | *<0.001* | *<0.001* | *<0.001* |

$^{a-b}$ Means with different superscripts in columns differ significantly (*P* ≤0.05).

While the weight of the fleece harvested at first shearing may be influenced by the body size at shearing, the wool growth rate of lambs may illicit a better indication of wool production characteristics (Table 8.2). A tendency was observed for ram lambs to have a higher growth rate per surface area than ewes (1.1 mg/cm$^2$/day and 1.0 mg/cm$^2$/day, respectively; *P* =0.070). The average monthly fleece growth and average wool growth rates of ram lambs (360.8 g and 11.4 g/day) were significantly higher than that of ewe lambs (299.8 g and 9.4 g/day). Merino lambs showed the highest growth rates (*P* ≤0.05) in terms of wool growth per surface area (1.4 mg/cm$^2$/day), average monthly fleece growth (409.5 g) and average wool growth rate (12.9 g/day). The wool growth rate of Dohne Merino and SAMM lambs did not differ (*P* >0.05) in terms of growth rate per surface area (~1.0 mg/cm$^2$/day), monthly fleece growth (~319.8 g) or average wool growth rate (~10.1 g/day). The wool growth of Dormer lambs was lower than that of the other breeds (*P* <0.05), producing 0.8 mg wool/cm$^2$/day, 272.0 g of wool each month at an average rate of 8.5 g/day. Although the average wool growth rate of Dormer lambs did not differ significantly from that of Dohne Merino lambs.

**Table 8.2** Least square means (± S.E.) of wool growth rate measures of ram and ewe lambs of different breeds measured over a 10 month period, recorded on a monthly basis.

| **Main effect** | | **Wool growth per surface area ($mg/cm^2/day$)** | **Calculated monthly fleece growth (g)** | **Calculated wool growth rate (g/day)** |
|---|---|---|---|---|
| Sex | Ewe | 1.0 ± 0.04 | 299.8 ± 11.47 | 9.429 ± 0.3816 |
| | Ram | 1.1 ± 0.03 | 360.8 ± 10.54 | 11.424 ± 0.3507 |
| | *P-value* | *0.070* | *<0.001* | *<0.001* |
| | | | | |
| Breed | Merino* | $1.4^{a}$ ± 0.07 | $409.5^{a}$ ± 23.21 | $12.9^{a}$ ± 0.7720 |
| | Dohne Merino** | $1.1^{b}$ ± 0.04 | $306.3^{b}$ ± 12.41 | $9.7^{bc}$ ± 0.4127 |
| | SAMM** | $1.0^{b}$ ± 0.04 | $333.3^{b}$ ± 11.92 | $10.6^{b}$ ± 0.3965 |
| | Dormer** | $0.8^{c}$ ± 0.04 | $272.0^{c}$ ± 11.68 | $8.5^{c}$ ± 0.3886 |
| | *P-value* | *<0.001* | *<0.001* | *<0.001* |

$^{a-b}$ Means with different superscripts in columns differ significantly (*P* ≤0.05).

* Calculated using formula: total fleece growth = 6.5 x *lamb weight*$^{2/3}$ *x wool mass from 100 cm*$^2$ *clipping*

** Calculated using formula: total fleece growth = 6 x *lamb weight*$^{2/3}$ *x wool mass from 100 cm*$^2$ *clipping*

In order to predict wool production of lambs of the different breeds, in terms of greasy or clean fleece weight, linear regressions were fitted to the calculated cumulative fleece weight data at the age and body weight of the lambs at sampling, which were used as predictors. The parameter estimators of the respective linear models were compared between the effects of sex and breed (Table 8.3). Models describing the increase in greasy fleece weight with age as predictor showed that the intercepts (*A* parameter) did not differ with sex (*P* =0.794), while the slopes (*B* parameter) of ram lambs (0.0115) was greater than ewe lambs (0.0096) (*P* <0.001). With regard to breed, Merino and Dohne Merino lambs showed higher (*P* ≤0.05) intercept values (~1.043) than Dormer and SAMM lambs (~0.121). Merino lambs also presented a steeper slope (0.0131) followed by SAMM (0.0105) and Dohne Merino (0.0098) lambs with Dormers having the shallowest slope (0.0086; *P* <0.001). Using weight as a predictor, neither the *A* nor *B* parameters vary with the effect of sex (*P* >0.05). The intercept value of Dohne Merino lambs (0.786) was markedly higher than that of Dormer and SAMM lambs (~0.082), while that of Merino lambs did not differ from that of the other breeds (0.690; *P* >0.05). Again, Merinos presented higher values for the regression slopes (0.0552) and Dormers the lowest values (0.0282; *P* ≤0.05). The *B* parameter estimator for Dohne Merinos (0.0385) differed from both Merinos and Dormers (*P* ≤0.05), but did not differ (*P* >0.05) from that of SAMM lambs (0.0340), which in turn differed from that of Merinos (*P* ≤0.05). In predicting the clean fleece production of the growing lambs, no differences were observed between rams and ewes for either of the parameter values when using age or body weight as a predictor ($P$ >0.05). When using age as a predictor of clean fleece weight, Merinos and Dohne Merinos present higher $A$ parameter estimates than Dormer or SAMM breeds (0.740 *vs.* 0.054; $P$ ≤0.05). Merinos also presented significantly higher slope values (0.0081) than the other breeds (~0.0060). With body weight being used as a predictor of clean fleece weight, the Dohne Merinos presented the highest $A$ estimate value (0.634) and Dormer and SAMM lambs the lowest (~0.042; $P$ ≤0.05), while that of Merinos (0.479) did not differ from the other breeds ($P$ >0.05). Similar to the previous models, the slope of the Merino lambs (0.0341) for predicting clean fleece weight from body weight was markedly higher than that of the other breeds, which did not differ from each other (~0.0207; $P$ >0.05).

**Table 8.3** Least square means (± S.E.) of linear ($Y = A + Bx$) parameter estimators for greasy and clean fleece weight with either age or body weight as predictors for wool growth of ram and ewe lambs of different breeds.

| **Main effect** | **Greasy fleece weight with age parameter estimates** | | **$R^2$** | **Clean fleece weight with age parameter estimates** | | **$R^2$** |
|---|---|---|---|---|---|---|
| | ***A*** | ***B*** | | ***A*** | ***B*** | |
| Ewe | 0.616 ± 0.1912 | $0.0096^b$ ± 0.00039 | 0.444 | 0.384 ± 0.1057 | 0.0062 ± 0.00030 | 0.479 |
| Ram | 0.548 ± 0.1764 | $0.0115^a$ ± 0.00036 | 0.439 | 0.408 ± 0.0989 | 0.0068 ± 0.00028 | 0.334 |
| *P-value* | *0.794* | *<0.001* | | *0.872* | *0.300* | |
| | | | | | | |
| Merino | $1.146^a$ ± 0.3843 | $0.0131^a$ ± 0.00079 | 0.616 | $0.758^a$ ± 0.2107 | $0.0081^a$ ± 0.00060 | 0.499 |
| Dohne | $0.940^a$ ± 0.2054 | $0.0098^{bc}$ ± 0.00042 | 0.504 | $0.722^a$ ± 0.1202 | $0.0060^b$ ± 0.00034 | 0.455 |
| SAMM | $0.130^b$ ± 0.1974 | $0.0105^b$ ± 0.00040 | 0.620 | $0.076^b$ ± 0.1082 | $0.0059^b$ ± 0.00031 | 0.550 |
| Dormer | $0.112^b$ ± 0.2046 | $0.0086^c$ ± 0. 00042 | 0.656 | $0.028^b$ ± 0.1154 | $0.0060^b$ ± 0.00033 | 0.686 |
| *P-value* | *0.005* | *<0.001* | | *<0.001* | *0.012* | |

| **Main effect** | **Greasy fleece weight with body weight parameter estimates** | | **$R^2$** | **Clean fleece weight with body weight parameter estimates** | | **$R^2$** |
|---|---|---|---|---|---|---|
| | ***A*** | ***B*** | | ***A*** | ***B*** | |
| Ewe | 0.388 ± 0.1825 | 0.0395 ± 0.00164 | 0.328 | 0.256 ± 0.0964 | 0.0252 ± 0.00121 | 0.375 |
| Ram | 0.432 ± 0.1683 | 0.0384 ± 0.00151 | 0.395 | 0.342 ± 0.0902 | 0.0230 ± 0.00114 | 0.252 |
| *P*-value | *0.858* | *0.613* | | *0.520* | *0.193* | |
| | | | | | | |
| Merino | $0.690^{ab}$ ± 0.3667 | $0.0552^a$ ± 0.00329 | 0.666 | $0.479^{ab}$ ± 0.1921 | $0.0341^a$ ± 0.00242 | 0.578 |
| Dohne | $0.786^a$ ± 0.1960 | $0.0385^b$ ± 0.00173 | 0.524 | $0.634^a$ ± 0.1096 | $0.0235^b$ ± 0.00138 | 0.427 |
| SAMM | $0.097^b$ ± 0.1883 | $0.0340^{bc}$ ± 0.00169 | 0.658 | $0.046^b$ ± 0.0986 | $0.0193^b$ ± 0.00124 | 0.478 |
| Dormer | $0.067^b$ ± 0.1952 | $0.0282^c$ ± 0.00175 | 0.678 | $0.038^b$ ± 0.1052 | $0.0193^b$ ± 0.00132 | 0.622 |
| *P*-value | *0.029* | *<0.001* | | *<0.001* | *<0.001* | |

$^{a\text{-}c}$ Means with different superscripts in columns differ ($P \leq 0.05$).

As it was seen that the wool growth rates between rams and ewes as well as between the breeds differed (Table 8.2), while parameter estimate values did not necessarily differ (Table 8.3). The model functions for predicting greasy fleece weight of each production group are presented in Table 8.4. As farmers primarily work with greasy fleece weight when evaluating wool yield rather than clean fleece weight, the functions in Table 8.4 were specifically developed to predict greasy fleece weight from either age or body weight of the lambs. Moderate to high $R^2$ coefficients of determination were obtained for the respective regression functions, indicating that a large portion of the variation is accounted for by the models. Functions for predicting fleece weight of Merino rams obtained the highest $R^2$ values with age (0.933) and body weight (0.852) as predictor. Lower $R^2$ coefficients were obtained by Dohne Merino lambs (0.453-0.543) and Merino ewes (0.553 and 0.581), while functions for Dormer and SAMM lambs accounted for 60-76% of the variation. Generally, using body weight to predict greasy fleece weight, produced functions with greater $R^2$ values than functions using age as a predictor.

**Table 8.4** Linear functions (with $R^2$ coefficients of determination) for estimating greasy fleece weight (*FW,* in kg) from age (*A,* in days) or body weight (*W,* in kg) of ram and ewe lambs from different breeds.

| **Breed** | **sex** | **Function with age** | **$R^2$** | **Function with body weight** | **$R^2$** |
|---|---|---|---|---|---|
| Merino | Ewe | $FW = 0.690 + 0.0122A$ | 0.553 | $FW = 0.238 + 0.0547W$ | 0.581 |
| | Ram | $FW = 1.601 + 0.0140A$ | 0.933 | $FW = 1.143 + 0.0558W$ | 0.852 |
| Dohne Merino | Ewe | $FW = 1.142 + 0.0093A$ | 0.543 | $FW = 0.904 + 0.0419W$ | 0.523 |
| | Ram | $FW = 0.738 + 0.0104A$ | 0.453 | $FW = 0.669 + 0.0352W$ | 0.523 |
| SAMM | Ewe | $FW = 0.307+0.0092A$ | 0.692 | $FW = 0.191 +0.0335W$ | 0.718 |
| | Ram | $FW = 0.0119A – 0.046$ | 0.628 | $FW = 0.003 + 0.0334W$ | 0.742 |
| Dormer | Ewe | $FW = 0.325 + 0.0076A$ | 0.661 | $FW = 0.220 + 0.0281W$ | 0.601 |
| | Ram | $FW = 0.0097A – 0.102$ | 0.669 | $FW = 0.0282W - 0.085$ | 0.769 |

It is also necessary to consider the yearling wool quality characteristics of the various production groups (Table 8.5) as well as that of their mature (2-4 years of age) dams (Table 8.6). Sex did not influence fibre diameter or its standard deviation (S.D.), coefficient of variation (C.V.), comfort factor or crimp frequency ($P$ >0.05; Table 8.5). However, the clean yield of ewe lambs was 8.6% higher than that of rams with ewes also presenting higher staple lengths than rams (146.69 *vs*. 130.80mm; $P$ ≤0.05). Wool samples from Dormer lambs had the thickest fibre diameters (31.3 µm), with the greatest S.D. (6.4) and C.V. (20.3%), with the lowest comfort factor (46.4%; $P$ ≤0.05). Following the Dormer lambs, wool from SAMM lambs presented a greater fibre diameter than that of Dohne Merino and Merino lambs (23.3 µm, 21.0 µm and 19.6 µm, respectively; $P$ ≤0.05). Wool samples from Dohne Merino, Merino and SAMM lambs did not differ significantly with respect to S.D. (~3.4), C.V (~16.0%) or comfort factor (97.8%). The clean yield of SAMM yearling wool was markedly lower than that of the Merino breed (56.5% *vs*. 61.9%, respectively). The staple length of yearling Merino wool was longer than that of SAMM wool (158.97 mm and 121.74 mm, respectively; $P$ ≤0.05), while that of Dohne Merino and Dormer wool did not differ from any of the breeds ($P$ >0.05). The Crimp frequency of the fibres did not vary with respect to sex ($P$ =0.395) or breed ($P$ =0.461), with an average frequency 11.1 crimps per inch.

The body weights of SAMM ewes were significantly higher than that of Dormer ewes, which were heavier than that of Dohne Merino and Merino ewes (88.0 kg, 80.7 kg, 73.5 kg and 71.5 kg, respectively; Table 8.6). Merino ewes produced the heaviest greasy (5.219 kg) and clean fleece weights (3.731 kg), followed by Dohne Merino (4.416 kg and 2.928 kg) and SAMM ewes (3.372 kg and 2.007 kg), which also produced heavier fleeces than Dormer ewes (2.758 kg and 1.571 kg) ($P \leq 0.05$). Merino ewes also presented higher clean yields, followed by Dohne Merinos, with wool from SAMM and Dormer ewes presenting the lowest clean yields (71.2%, 66.3%, 59.3% and 56.2%, respectively; $P \leq 0.05$).

Similar to yearling lambs, Merino and Dohne Merino ewes produced the finest wool with 18.3μm diameters followed by SAMM ewes (21.8 μm) and the Dormer breed producing the coarsest fibres (27.9 μm; $P \leq 0.05$). Wool from Dormers had higher ($P \leq 0.05$) standard deviations (5.3) for fibre diameter than that from SAMM ewes (3.9) which in turn was higher than Dohne Merino (3.3) and Merino ewes (3.0). The coefficients of variation for fibre diameter were lowest ($P \leq 0.05$) for wool from Merino ewes (16.3%) than for wool from the other breeds (~18.3%). Similar to the wool from yearling lambs, wool from Dormer sheep presented a significant lower comfort factor than the other breeds (68.8% *vs.* 99.1%). Wool from Merino wool also had a longer staple length than SAMM and Dormer wool (158.73 *vs.* 131.74 mm and 125.90 mm, respectively; $P \leq 0.05$). The staple length of Dohne Merino ewes (146.61 mm), did not differ from that of Merino and SAMM ewes ($P > 0.05$), though it did differ from that of Dormer ewes. Merino and Dohne Merino wool samples also displayed a significantly lower crimp frequency than that of SAMM and Dormer samples (12.5, 11.8, 18.2 and 18.4 crimps per inch, respectively).

**Table 8.5** Least square means (± S.E.) of wool quality traits of year old ram and ewe lambs of different South African wool sheep breeds.

| **Main effect** | | **Fibre diameter (µm)** | **Standard deviation of fibre diameter** | **Coefficient of variation of fibre diameter (%)** | **Comfort factor (%)** | **Clean yield (%)** | **Staple length (mm)** | **Crimp frequency (crimps per inch)** |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 23.7 ± 0.52 | 4.2 ± 0.18 | 17.4 ± 0.43 | 85.1 ± 2.33 | 65.4 ± 1.84 | 146.69 ± 5.621 | 11.7 ± 1.00 |
| | Ram | 23.9 ± 0.49 | 4.1 ± 0.17 | 16.7 ± 0.44 | 84.8 ± 2.19 | 59.8 ± 1.73 | 130.80 ± 5.183 | 10.5 ± 0.92 |
| | *P-value* | *0.798* | *0.727* | *0.265* | *0.912* | *<0.001* | *0.042* | *0.395* |
| Breed | Merino | $19.6^{c}$ ± 1.03 | $3.1^{b}$ ± 0.37 | $15.6^{b}$ ± 0.94 | $99.6^{a}$ ± 4.65 | $61.9^{a}$ ± 3.68 | $158.97^{a}$ ± 11.295 | 10.3 ± 2.01 |
| | Dohne Merino | $21.0^{c}$ ± 0.59 | $3.4^{b}$ ± 0.21 | $16.0^{b}$ ± 0.53 | $96.9^{a}$ ± 2.66 | $62.5^{ab}$ ± 2.10 | $141.67^{ab}$ ± 6.037 | 10.5 ± 1.07 |
| | SAMM | $23.3^{b}$ ± 0.53 | $3.8^{b}$ ± 0.19 | $16.4^{b}$ ± 0.48 | $96.9^{a}$ ± 2.38 | $56.5^{b}$ ± 1.89 | $121.74^{b}$ ± 5.801 | 12.6 ± 1.03 |
| | Dormer | $31.3^{a}$ ± 0.57 | $6.4^{a}$ ± 0.20 | $20.3^{a}$ ± 0.51 | $46.4^{b}$ ± 2.55 | $69.6^{ab}$ ± 2.01 | $132.61^{ab}$ ± 6.012 | 11.0 ± 1.07 |
| | *P-value* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *<0.001* | *0.018* | *0.461* |

$^{a\text{-}c}$ Means with different superscripts in columns differ significantly (*P* ≤0.05).

**Table 8.6** Least square means (± S.E.) of wool quality traits of mature dam ewes of different South African wool sheep breeds with a year old fleece.

| **Trait** | **Merino** | **Dohne Merino** | **SAMM** | **Dormer** | ***P-value*** |
|---|---|---|---|---|---|
| Body weight | 71.5$^{c}$ ± 1.54 | 73.5$^{c}$ ± 1.39 | 88.0$^{a}$ ± 1.57 | 80.7$^{b}$ ± 1.61 | *<0.001* |
| Greasy fleece weight (kg) | 5.219$^{a}$ ± 0.1300 | 4.416$^{b}$ ± 0.1172 | 3.372$^{b}$ ± 0.1326 | 2.758$^{c}$ ± 0.1353 | *<0.001* |
| Clean fleece (kg) | 3.731$^{a}$ ± 0.1064 | 2.928$^{b}$ ± 0.0959 | 2.007$^{b}$ ± 0.1085 | 1.571$^{c}$ ± 0.1107 | *<0.001* |
| Fibre diameter (µm) | 18.3$^{c}$ ± 0.34 | 18.2$^{c}$ ± 0.31 | 21.8$^{b}$ ± 0.35 | 27.9$^{a}$ ± 0.36 | *<0.001* |
| Standard deviation of fibre diameter | 3.0$^{c}$ ± 0.09 | 3.3$^{c}$ ± 0.09 | 3.9$^{b}$ ± 0.10 | 5.3$^{a}$ ± 0.10 | *<0.001* |
| Coefficient of variation of fibre diameter (%) | 16.3$^{b}$ ± 0.41 | 18.0$^{a}$ ± 0.37 | 17.9$^{a}$ ± 0.42 | 19.1$^{a}$ ± 0.43 | *<0.001* |
| Comfort factor (%) | 99.7$^{a}$ ± 1.78 | 99.5$^{a}$ ± 1.61 | 98.0$^{a}$ ± 1.82 | 68.8$^{b}$ ± 1.86 | *<0.001* |
| Clean yield (%) | 71.2$^{a}$ ± 1.25 | 66.3$^{b}$ ± 1.12 | 59.3$^{c}$ ± 1.27 | 56.2$^{c}$ ± 1.30 | *<0.001* |
| Staple length (mm) | 158.73$^{a}$ ± 4.091 | 146.61$^{ab}$ ± 3.688 | 131.74$^{bc}$ ± 4.172 | 125.90$^{c}$ ± 4.258 | *<0.001* |
| Crimp frequency (crimps per inch) | 12.5$^{b}$ ± 0.43 | 11.8$^{b}$ ± 0.39 | 18.2$^{a}$ ± 0.44 | 18.4$^{a}$ ± 0.45 | *<0.001* |

$^{a-c}$ Means with different superscripts in rows differ significantly ($P$ ≤0.05).

## 8.4 Discussion

The Merino is well distinguished as a wool breed, producing heavy fleeces with a medium to fine fibre diameter, depending on the Merino line used (Hogan *et al*., 1979). The Dohne Merino and South African Mutton Merino are considered to be dual-purpose breeds, with the Dohne Merino orientating towards wool production while the Mutton Merino tends towards lamb-meat production. While both of these breeds find their roots from the German Mutton Merino, which was imported into South Africa in 1932, the Dohne Merino also contains Merino ancestry and so presents better wool production characteristics (Cloete *et al*., 1998; Cloete *et al*., 2001). The Dormer, on the other hand, is considered to be a terminal sire meat breed, which was developed by crossing Dorset-horn rams with German mutton Merino ewes (Van Wyk *et al*., 2003). The result of this is a large framed sheep with good conformation and high growth rates that produces wool with a coarse fibre diameter (>27 µm).

In this study, Merino sheep produced the heaviest fleeces, both mature ewes as well as yearlings, and as expected the Merino lambs exhibited higher wool growth rates. Although, these wool growth rates for Merino lambs were low when compared to the study by Du Plessis & De Wet (1981) who reported wool growth of 27.13 g/sheep/day. While the low number of Merino lambs in this study cannot be considered to be representative of the variation in wool growth in Merino lambs; these rates still resemble that of Merino stud ewes of different genotypes (11.81- 20.00 g/day) (Hogan *et al*., 1979). Cloete *et al*. (2005) observed in divergently selected Merino lines that wrinkle score was negatively correlated with live weight (-0.26) and showed that in the line with higher breeding values for live weight, there was also a decrease in wrinkle score. The lambs used in the current study were obtained from a flock where selection for growth traits were implemented, and so the Merinos in this study could possibly have had lower wrinkle scores than other genotypes that were selected for wool production, thereby not attaining high wool growth rates.

Though not significant, Dohne Merinos did produce heavier fleece weights than SAMMs in this study, with wool growth rates also not differing significantly. Cloete *et al*., (2001) and Cloete *et al*. (2003) showed that Dohne Merino yearlings and ewes do produce heavier fleeces than that of the SAMM breed. The lack of differences observed between the Dohne Merino and SAMM breeds may be as a result of the differences in body weight compensating for the fleece weight of SAMM sheep to resemble that of Dohne Merinos. Van Wyk *et al*. (2008) observed a moderately positive correlation between yearling weight and clean fleece weight (r =0.316) in Dohne Merinos, indicating that an increase in body weight can be associated with an increase in fleece weight. However, the wool growth rate and wool growth per surface area also did not show any significant differences between the Dohne Merino and SAMM lambs, indicating that the lack of difference in fleece weights are due to the breeds exhibiting similar wool growth rates. The wool growth rates of these dual-purpose breeds were also slightly lower than that obtained by Du Plessis & De Wet (1981) who recorded rates of 14.59 and 16.71 g/day for Dohne Merino and SAMM wethers. As expected, the Dormer breed that has not been selected for wool production, had the lowest fleece production. In yearlings, ram lambs presented greater wool growth than ewe lambs.

In order to predict the fleece yield of growing lambs of the different breeds, linear regressions were constructed using age or body weight of lambs as a predictor (Tables 8.3 and 4). These estimations were constructed by subtracting the cumulative monthly wool growth from the yearling fleece weight. These linear models account for more than 50-60% of the variation of the data. The high $R^2$ values obtained by the Merino lamb group can be explained by the low number of animals in this study limiting the rane of the variation. It is recommended that this study be repeated for Merino lambs, taking the different Merino lines (superfine, fine and medium fibre diameter) into account. These models can be used by producers in order to estimate the weights of greasy or clean fleece that can be obtained from growing lambs at different stages before they attain a mature body weight. Previous models, aimed to predict wool production according to the nutrient intake and utilisation of energy and nitrogen for wool growth (Arnold *et al*., 1977; Finlayson *et al*., 1995). These models, however, do not account for the change in fleece yield in growing lambs.

With regard to quality traits of the wool sample from the different breeds Merino yearling and dams produced wool with the finest fibre diameters (<20 μm), with the lowest level of variation between the fibres. Yearling Dohne Merino and SAMM lambs produced wool with a medium fibre diameter, while that of Dohne Merino lambs was significantly finer than SAMM wool. In the mature ewe dams, the Dohne Merino wool samples presented a fine fibre diameter, similar to that of the Merino ewes (18 μm), while SAMM ewes produced wool with a medium fibre diameter. Dormer sheep produced wool with a coarse fibre diameter (>27 μm) and a low comfort factor. Such coarse wools with low comfort factors are not suitable for fabrics that have direct contact with the skin, as they present irritations, thus these wools are more suited for the manufacturing of carpets and blankets. Cloete *et al.* (2001) reported fibre diameters of 21.9, 21.8 and 23.7 μm for Merino, Dohne Merino and SAMM yearlings, respectively; while in different ewe dam lines, Cloete *et al.* (2003) reported diameters of 22.8-23.3 μm for different Merino lines, 22.1 μm for Dohne Merinos and 23.7 μm for SAMM ewes. The national average fibre diameter for Dohne Merino stud ewes was reported to be 19.4 μm (Van Wyk *et al*., 2008). Snyman *et al*. (1998) reported that fibre diameter of Merino ewes varied (19.8-23.0 μm) between different South African research flocks. Unfortunately no published literature could be found regarding wool traits of Dormer sheep, though its ancestor, the Dorset-horn also produces coarse wool with fibre diameters greater than 29.0 μm (Steinhagen *et al*., 1986).

The clean yield of Merino ewe wool remains fairly similar to previous studies from the Elsenburg flocks ranging from 71-74% (Brand, *et* al., 1999; Cloete *et al*., 2003; Matebesi-Ranthimo *et al*., 2017). The clean yield of Dohne Merino is estimated to be ~68% (Steinhagen & De Wet, 1986; Cloete *et al*., 2003). The clean yield of the SAMM breed has also been presented as 60-64% of the greasy fleece weight (Brand *et al*., 1999; Cloete *et al*., 2003). The yields for Dohne Merino and SAMM fleeces in this study were slightly lower than that observed in literature. Clean yields for fleece produced from Dormer sheep have not yet been documented with this study noting clean yields of 69.6% for yearlings and 56.2% for ewes. As expected, Merino wool samples had higher staple lengths than Dohne Merino wool followed by SAMM and Dormer wool. The staple lengths of wool from the yearling lambs resembled that of the ewes from the respective breeds, which were previously shorn 12 months prior. The crimp frequency was traditionally used as an indirect selection criterion for fibre diameter; however, it has a greater association with fibre curvature (Hatcher & Atkins, 2000). An increase in curvature may result in an increase in the incidence of fibre breakages (Holman & Malau-Aduli, 2012). Wool from yearling lambs of different breeds did not vary with respect to crimp frequency. However, in mature ewes, Merino and Dohne Merino wool displayed lower crimp frequencies than Dormer and SAMM wool. Merino and Dohne Merino wool is thus expected to display less curvature and so should be less susceptible to fibre breakage.

As the Merino is a popular wool producing breed, it is unsurprising that wool growth rates, staple lengths and fleece weights are greater than the other breeds; while also presenting superior wool quality characteristics in terms of a greater clean yield, finer fibre diameter and low crimp frequency. In this study, wool growth rates of Dohne Merino lambs, as well as fleece weights, did not differ ($P \leq 0.05$) from that of SAMM lambs, although staple lengths of Dohne Merino wool was longer than that of SAMM wool. The SAMM yearlings and mature ewes were respectively heavier than their Dohne Merino counterparts, atherefore the size of the sheep may have offset differences in fleece weight. As staple lengths do differ, it is expected that when correcting for body weight, Dohne Merinos should produce a heavier fleece than SAMM sheep. Dormer sheep have not specifically been bred for wool production and thus produce a lighter fleece with a coarser fibre diameter. As Dormer lambs are primarily slaughtered at a young age, soon after weaning, the income derived from wool production would be negligible. The wool from Dormer ewes, despite having a lower financial value, can be utilised.

## 8.5 Conclusion

The wool production characteristics of four different breeds were assessed in order to determine the wool growth rates of growing lambs. As anticipated, the Merino being a predominant wool breed exhibited superior wool growth characteristics followed by the Dohne Merino and SAMM breeds. The Dormer, being bred for meat production, on the other hand produced less wool, at a slower rate with a coarser fibre diameter. Linear models were constructed in order to assist producers in predicting wool growth for growing lambs of the respective breeds. The results of this study present guidelines for producers that can be used to predict the financial contribution of wool for the different breeds as well assist in predicting the wool yield at a given age or weight.

It is suggested that the study should be repeated in order to increase the database and obtain more reliable estimates. In particular, this should be performed for Merino lambs, while also taking into account different Merino lines found in South Africa which vary in wool production.

## References

Arnold, G.W., Campbell, N.A., Galbraith, K.A., 1977. Mathematical relationships and computer routines for a model of food intake, liveweight change and wool production in grazing sheep. Agric. Syst., 2, 209-226.

Brand, T.S., Franck, F., Coetzee, J., 1999. Kikuyu (*Pennisetum clandestinum*) pasture for sheep. 2. Production and nutritional status of ewes with or without lupin (*Lupinus albus*) supplementation. New Zeal. J. Agric. Res. 42, 467-474.

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci., 47, 26-33.

Çam, M.A., Olfaz, M., Garipoglu, A.V., 2007. Shearing male lambs in the cold season improves the carcass yield without affecting fattening performance. Jpn. Anim. Sc. J., 78, 259–265.

Cloete, J.J.E,. 2007. Evaluation of the South African small stock genetic resources for production and meat quality traits. PhD Agric. Thesis. Stellenbosch University, South Africa.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2008. Carcass characteristics and meat quality of progeny of five Merino dam lines, crossed with Dormer and Suffolk sires. S. Afr. J. Anim. Sci., 38, 355-366.

Cloete, S.W.P., Cloete, J.J.E., Durand, A., Hoffman, L.C., 2003. Production of five Merino type lines in a terminal crossbreeding system with Dormer or Suffolk sires. S. Afr. J. Anim. Sci., 33, 223-232.

Cloete, S.W.P., Olivier, J.J., Sandenbergh, L., Snyman, M.A., 2014. The adaption of the South Africa sheep industry to new trends in animal breeding and genetics: A review. S. Afr. J. Anim. Sci., 44, 307-321.

Cloete, S.W.P., Schoeman, S.J., Coetzee, J., Morris, J.D.V., 2001. Genetic variances for liveweight and fleece traits in Merino, Dohne Merino and South African Meat Merino sheep. Aust. J. Exp. Agric., 41, 145-153.

Cloete, S.W.P., Scholtz, A.J., Aucamp, B.B., 1998. Environmental effects, heritability estimates and genetic trends in a Western Cape Dohne Merino nucleus flock. S. Afr. J. Anim. Sci., 28, 185-195.

Cloete, S.W.P., Olivier, J.J., van Wyk, J.B., Schoeman, S.J., Erasmus G.J., 2005. Genetic parameters and trends for hogget traits in Merino lines divergently selected for multiple rearing ability. Proc. Assoc. Advmt. Anim. Breed. Genet. 16, 24-27.

Cloete, S.W.P., van Wyk, J.B., Neser, F.W.C., 2004. Estimates of genetic and environmental (co) variances for live weight and fleece traits in yearling South African Mutton Merino sheep. S. Afr. J. Anim. Sci., 34, 37-43.

Cronje, P.B., Weites, E., 1990. Live mass, carcass and wool growth responses to supplementation of a roughage diet with sources of protein and energy in South African Mutton Merino lambs. S. Afr. J. Anim. Sci., 20, 161-168.

Department of Agriculture, Forestry & Fisheries. 2018. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-63. (https://www.daff.gov.za/Daffweb3/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202018.pdf).

Du Plessis, J.J., 1974. The utilisation of nitrogen by three sheep types for wool and meat production (translated from Afrikaans). MSc Agric. Thesis. Stellenbosch University, South Africa.

Du Plessis, J.J., De Wet, P.J., 1981. Nitrogen utilization by sheep. 1. Nitrogen utilization by weaned lambs of a wool, a wool/mutton and a mutton/wool breed for wool and body protein formation. Agroanimalia, 13, 21-27.

Ferguson, K.A., 1958. The influence of thyroxine on wool growth. Proc.18th Ann. Conf. New Zeal. Soc. Anim. Prod., 18, 128-140.

Finlayson, J.D., Cacho, O.J., Bywater, A.C., 1995. A simulation model of grazing sheep: I. Animal growth and intake. Agric. Syst., 48, 1-25.

Hatcher, S., Atkins, K.D., 2000. Breeding objectives which include fleece weight and fibre diameter do not need fibre curvature. Asian Austral. J. Anim. Sci., 13, 293-296.

Hogan, J.P., Elliott, N.M., Hughes, A.D., 1979. Maximum wool growth rates expected from Australian Merino genotypes. In: Black, J.L., Reis, P.J., (Eds). Physiological and environmental limitations to wool growth. pp 43-59.

Holman, B.W.B., Malau-Aduli, A.E.O., 2012. A review of sheep wool quality traits. Ann. Rev. Res. in Biol., 2, 1-14.

Holst, P., Hopkins, D., Stanley, D., 1996. Time required post-shearing to attain desirable wool lengths for lambskins from different genotypes. Wool Tech. Sheep Breed. 44, 290-294.

Langlands, P., Wheeler, L., 1968. The dye banding and tattooed patch procedures for estimating wool production and obtaining samples for the measurements of fibre diameter. Anim. Prod. Sci. 8, 265–269.

Matebesi-Ranthimo, P.A.M., Cloete, S.W.P., van Wyk, J.B., Olivier, J.J., 2017. Genetic parameters for ewe reproduction with objectively measured wool traits in Elsenburg Merino flock. S. Afr. J. Anim. Sci., 47, 712-722.

Sneddon, J., Rollin, B., 2010. Mulesing and animal ethics. J. Agric. Environ. Ethics, 23, 371-386.

Snyman, M.A., Cloete, S.W.P., Olivier, J.J., 1998. Genetic and phenotypic correlations of total weight of lamb weaned with body weight, clean fleece weight and mean fibre diameter in three South African Merino flocks. Livest. Prod. Sci., 55, 157-162.

Steinhagen, O., De Wet, P.J., 1986. The influence of age and generation number of the Döhne Merino on different wool production traits. S. Afr. J. Anim. Sci., 16, 101-102.

Steinhagen, O., Dreyer, J.H., Hofmeyr, J.H., 1986. Histological differences in the skin and fibre characteristics of ten white-woolled sheep breeds. S. Afr. J. Anim. Sci., 16, 90-94.

Van der Merwe, D.A., Brand, T.S., Hoffman, L.C., 2019. Application of growth models to different sheep breed types in South Africa. Small Rumin. Res., 178, 70-78.

Van der Westhuizen, L., Magwaba, T., Grobler, J.P., Bindeman, H., du Plessis, C., van Marle-Köster, E., Neser, F.W.C., 2019. Genetic variability in a population of Letelle sheep in South Africa. S. Afr. J. Anim. Sci. 49, 281-289.

Van Wyk, J.B., Fair, M.D., Cloete, S.W.P., 2003. Revised models and genetic parameter estimates for production and reproduction traits in the Elsenburg Dormer sheep stud. S. Afr. J. Anim. Sci., 33, 213-222.

Van Wyk, J.B., Swanepoel, J.W., Cloete, S.W., Olivier, J.J., Delport, G.J., 2008. Across flock genetic parameter estimation for yearling body weight and fleece. S. Afr. J. Anim. Sci., 38, 31-37.

# Chapter 9 - Sheepskin leather quality characteristics of South African breeds


### Abstract

In order to investigate the physical leather quality characteristics of different sheep breeds, skins were obtained from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, South African Mutton Merino (SAMM) and White Dorper yearlings from two separate growth studies. The cured skins were stored for 18 months (Group 1) and 9 months (Group 2) prior to tanning. After tanning, samples from the butt region of the skins were taken to determine the tensile strength and distension properties. While sex, was found to have little effect ($P$ >0.05) on the physical characteristics of the leather in both groups, breed was found to have a more defined effect. Leather samples from White Dorper, Meatmaster and Dorper sheep had higher tensile strengths than that of wool breeds (~15.23 N/mm$^2$ *vs.* ~9.31 N/mm$^2$, respectively; $P$ ≤0.05). In both production groups, White Dorper skins exhibited the highest breaking force (207.3 N and 280.5 N) and percentage elongation at break (103.5% and 77.2%). Alternatively, Merino, SAMM, Dohne Merino and Dormer skins showed weaker properties which reduced the extent to which these skins could be shaved without breaking, resulting in thicker leather with weaker characteristics than that of the hair sheep breeds. The leather properties of hair sheep breeds more closely resemble the industry stipulations for nappa leather products; while skins from wool breeds of poorer quality are less desirable and may require different tanning processes to achieve an improved product.


**Keywords:** *Hair sheep; Wool sheep; Tanning; Leather thickness; Tensile strength*

## 9.1 Introduction

The primary products derived from sheep production are meat and wool, with lamb meat currently contributing the greater portion to the gross income. Lamb carcasses dress out at 48-50% of the live weight prior to slaughter, depending on which components are still viewed as part of the carcass (Notter *et al*., 1991; Brand *et al*., 2017). The offal components removed at slaughter are considered as the fifth quarter of the carcass and contribute to the income obtained by an abattoir, being sold as either edible products or skins sold to tanneries. The skins are flayed from the carcass during slaughter and can make up 7-13% of the slaughter weight of the lamb (Tshabalala *et al*., 2003; Ekiz *et al*., 2013). The variability of skin weight is dependent on the size and breed of the sheep as well as on the level of wool, or hair, cover (Jacinto *et al*., 2011). After slaughter, the skins are salted (cured), to reduce moisture and preserve the skin, and then sold to tanneries in order to be processed into a high value leather product.

In South Africa sheep skins are classed as either Dorper (hair breeds) or Merino (skins), with the different levels of wool growth often also being differentiated. The reason for this classification is that leather obtained from Merino sheepskins presents poorer mechanical properties than other sheep types (Snyman & Jackson Moss, 2000). However, Merino skins can be used for wool-on tanning rather than nappa processing in order to produce bed underlays, medical rugs and fleeced footwear (Holst *et al*., 1997). Due to the ribbiness of Merino skins, lime split of the grain layer is done to produce chamois leather from the skins. Nappa leather from sheep can be processed into clothing, gloves and slippers, and industrial gloves, though most of the leather produced in South Africa is exported (Ballard, 2001). In South Africa, sheepskins are produced primarily with the focus on the exports, exporting ~19 000 tonnes of skins annually between 2008 to 2017 (DAFF, 2019). The demand for leather products experiences fluctuations which influence the prices offered for the skins at the abattoir. As the abattoirs and lamb producers are not able to control the price of the skins that they market, it is important to be aware of how the leather quality characteristics of different sheep types differ. This then allows for grouping skins of uniform types to improve marketing to leather processors.

The aim of this study is thus to elaborate on the nappa leather (full grain, soft smooth leather) quality characteristics of fattened yearlings of different hair (Dorper, White Dorper and Meatmaster) and wool (Dohne Merino, Dormer, Merino, SA Mutton Merino) type breeds.

## 9.2 Materials and methods

### 9.2.1 Animal management

This study was carried out under the approval of the Western Cape Department of Agriculture's Departmental Ethics Committee for Research on Animals (DECRA R14/110). Ram and ewe yearlings from Dohne Merino, Dormer, Dorper, Meatmaster, Merino, South African Mutton Merino (SAMM) and White Dorper breeds, that were reared under feedlot conditions from weaning (100 days of age) until one year of age, were slaughtered and their skins were tanned into leather. The animals that were used to supply skins for this study were derived from the feed intake trial (Chapter 4) and the ultrasound fat depth trial (Chapter 5). The descriptions of the animal management, nutrition and numbers in the trials are outlined in the respective chapters. Sheep from the feed intake trial ($n$ =54) will henceforth be referred to as Group 1 and sheep from the fat depth trial ($n$ =131) referred to as Group 2. Aside from the sheep in Group 1 being individually fed, while sheep in Group 2 were group fed, the main contrast in management applied was that lambs in Group 1 were not shorn during the study period, while wool lambs (Dohne Merino, Dormer, Merino and SAMM) in Group 2 were shorn one month prior to slaughter. At about one year of age, the sheep were slaughtered at a registered commercial abattoir according to standard South African protocols. The sheep were electrically stunned (200 V for 5 s) in order to render them unconscious before they were immediately exsanguinated. After removal of the heads and trotters, the skins were flayed off the carcasses, identified and weighed. The skins were then salted by hand with minimum ratio of 1:1 coarse salt to skin weight. Skin yield was determined as the weight of the skin after slaughter expressed relative to the slaughter weight of the sheep.

### 9.2.2 Skin processing

The skins were allowed to dry under roof with no direct sunlight. The Group 1 skins were dried and stored for 18 months prior to tanning, while Group 2 skins were tanned after being dried and stored for 9 months. The skins were tanned at the International School of Tanning Technology (Grahamstown, South Africa), with skins for Groups 1 and 2 being tanned in two separate batches, according to the trial groups, but were processed in the same manner (Table 9.1 and 9.2). All of the skins from the same batch were processed together in the same drum, so as to standardise processing methods. The procedures for processing the raw skins are outlined in Table 9.1, and after drying and shaving the damp wet blues to a thickness of about 0.7-0.9 mm, the wet blues were retanned and dyed into black leather crusts (Table 9.2). Due to the ribbiness and delicateness of sheepskins of the wool breeds, the flesh of these skins could not be shaved down to the appropriate thickness (Snyman & Jackson-Moss, 2000).

**Table 9.1** Processing procedure of raw sheepskins to wet blue.

| Process | Temperature (°C) | Time | Chemical | Proportion of skin weight (%) | Remarks |
|---|---|---|---|---|---|
| Static soak | | Overnight | | | |
| Paint Dehair | | | 10ℓ, 3 kg lime, 1.5 kg Sodium sulphide | | |
| Liming | 25 | | Water | 100 | |
| | | | + $Na_2S$ | 2 | |
| | | | + CaO | 2 | |
| | | Overnight | + NaOH | 1 | |
| | | | | | Drain |
| | 25 | | Water | 100 | |
| | | | + $Na_2S$ | 1 | |
| | | | + CaO | 1 | |
| | | Overnight | + NaOH | 0.5 | |
| | | | | | Drain |
| Wash | 20 | | Water | 100 | |
| | | 10 minutes | + Degreaser | 1 | |
| | | | | | Drain |
| Wash (x2) | | | Water | 100 | |
| | | | + $(NH_4)_2SO_4$ | 1 | |
| | | 15 minutes | + Degreaser | 1 | |
| | | | | | Drain<br>Batch reweighed |
| Delime/Bate | 25 | | Water | 50 | |
| | | | + $(NH_4)_2SO_4$ | 3 | |
| | | | + Degreaser | 0.5 | |
| | | 30 minutes | + $Na_2S_2O_5$ | 0.5 | |
| | | 15 minutes | + $CH_2O_2$ | 0.3 | If necessary to ensure pH 8.0-9.0 |
| | 38 | | Water | 100 | |
| | | 60 minutes | + Alkaline bate | 0.5 | |
| | | | | | Drain |
| Degrease (x2) | 38 | | Water | 50 | |
| | | | + Paraffin | 5 | |
| | | 30 minutes | + Degreaser | 3 | |
| | | | | | Drain |
| Wash (x2) | 25 | | Water | 100 | |
| | | | + NaCl | 6 | |
| | | | + Degreaser | 1 | |
| | | | | | Drain |
| Pickle/Tan | 25 | | Water | 40 | |
| | | 10 minutes | + NaCl | 7 | |
| | | | + $CHO_2Na$ | 0.8 | |
| | | 60 minutes | + $H_2SO_4$ | 1.5 | pH= 2.0-2.5 |
| | | | + Chrome | 5.5 | |
| | | 60 minutes | + Fungicide | 0.1 | |
| | | Overnight | + MgO | 0.55 | pH= 3.6-4.0 |
| | | | | | Drain |
| Wash | 35 | | Water | 100 | |
| | | 20 minutes | + Fungicide | 0.1 | |
| | | | | | Drain |
| Horse up | | | | | |

**Table 9.2** Processing procedure of shaved wet blue into dyed leather crust.

| Process | Temperature (°C) | Time | Chemical | Proportion of skin weight (%) | Remarks |
|---|---|---|---|---|---|
| Wet back | 25 | | Water | 300 | |
| | | | + Degreaser | 1 | |
| | | 60 minutes | + Paraffin | 3 | |
| | | | | | Drain |
| Degreaser | 25 | | Water | 100 | |
| | | | + Degreaser | 1 | |
| | | 60 minutes | + Paraffin | 3 | |
| | | | | | Drain |
| Wash | 25 | | Water | 150 | |
| | | | + Degreaser | 1 | |
| | | 30 minutes | + $CH_2O_2$ | 0.5 | |
| | | | | | Drain |
| Rechrome | 25 | | Water | 150 | |
| | | | + Chrome syntan | 5 | |
| | | 60 minutes | + Fatliquor | 2 | |
| | | 60 minutes | + $NaHCO_3$ | 3 | |
| | | | | | Drain |
| Wash | | 15 minutes | Water | 150 | |
| | | | | | Drain |
| Fatliquor | 25 | | Water | 150 | |
| | | | + Pickle stable fatliquor | 2 | |
| | | 60 minutes | + Fatliquor | 4 | |
| | | 15 minutes | + $CH_2O_2$ | 1 | |
| | | 15 minutes | + $CH_2O_2$ | 1 | |
| | | | | | Drain |
| Wash | | | Water | 150 | |
| | | 15 minutes | + Fungicide | 0.1 | |
| Dry | | | | | Drain |
| Wet back | 25 | | Water | 500 | |
| | | 30 minutes | + Ammonia | 1 | |
| Dye | | 90 minutes | + Black dye | 4 | |
| Fatliquor | | 60 minutes | + Fatliquor | 5 | |
| | | 20 minutes | + $CH_2O_2$ | 1 | |
| | | 20 minutes | + $CH_2O_2$ | 1 | |
| | | 20 minutes | + $CH_2O_2$ | 1 | |
| | | | | | Drain |
| Wash (x3) | | 20 minutes | Water | 150 | |
| | | | | | Drain |

### 9.2.3 Leather quality tests

After tanning, the skins were sprayed with an acrylic-polyurethane resin mixture followed by a nitrocellulose lacquer top coat. Samples from the butt region of each crust were taken for analysis of leather quality traits. The characteristics of quality traits of tanned leather were analysed according to ISO methods (ISO, 2002a; 2002b; 2002c). The lastometer distension was determined as the point when the leather grain surface is ruptured by a steel ball (6.25 mm in diameter) which is pushed against the flesh side, at a constant force, of a clamped circular sample with a diameter of 25 mm. Tensile strength tests were measured on leather strip replicates (110 mm x 10 mm) cut from the butt sample, parallel to the direction of the spine. The leather strips were conditioned at 20°C and 65% relative humidity for 48 hours prior to testing. Before testing the width and thickness of the leather strips were measured using an electronic calliper. Tensile strength tests were performed with an Instron universal testing machine (Instron model 4444/H1028, Apollo Scientific cc, South Africa), set with jaws arranged 50 mm apart for standard testing and jaws separating at a rate of 100 mm/min. The greatest force recorded was taken as the breaking force (N) and the distance between the jaws at break relative to the original distance was taken as the percentage extension at break. The tensile strength ($N/mm^{2)}$ was calculated as the breaking force per area (width by thickness) of the strip.

### 9.2.4 Statistical analysis

The data were analysed using SAS enterprise guide (SAS version 7.1). Due to the differences in pre-slaughter management, skin drying and storage time and processing, the separate batches of Groups 1 and 2 were analysed separately. The General linear models procedure of SAS enterprise guide (SAS version 7.1) was used to test the main effects of sex and breed, as well as the interaction between the effects, on the skin and leather traits of each group using type three sum of squares. Due to low numbers of Merino sheep ($n$= 5) in Group 2, the data from the Merino breed was not included in the analysis. The Boneferroni method was used to determine significant differences between the main effects at the 95% level ($P$ ≤0.05) and tendencies were indicated at the 90% confidence level ($P$ ≤0.10)., Results are presented as least square means with accompanying standard errors. The data from Group 2 was also pooled according to wool and hair type sheep so as to determine the differences in leather quality of the two sheep types which skins are sorted into at slaughter.

## 9.3 Results

Sheepskin leather from both production groups showed no interactions between the main effects of sex and breed ($P$ >0.05). The leather quality characteristics of skins from the unshorn sheep (Group 1), that were stored for ~18 months before tanning, are presented in Table 9.3. The results of the Group 2 sheepskins which were dried (stored for ~9 months), processed and statistically analysed separately are presented in Table 9.4.

Observing the skins obtained from Group 1 (Table 9.3), the effect of sex only influenced the distension at crack ($P$ =0.014) with skin from rams being extended further than ewes (12.37 mm and 11.42 mm, respectively). The remaining traits did not show any significant differences between skins from ewe and ram yearlings. The highest ($P$ <0.001) skin yields were observed for Dohne Merino (14.1%) and Merino (13.4%) breeds, followed by Dormer (9.9%), which in turn was greater than that of Dorper (7.9%). The skin yields after slaughter of Meatmaster, SAMM and White Dorper breeds did not differ from that of Dormer or Dorper breeds ($P$ >0.05).

The thickness of the leather samples was thickest for Merino sheep (3.07 mm), which did not differ ($P$ >0.05) from that of Dohne Merino (2.55 mm) sheep, but differed significantly from the other breeds, with the Dorper skins being the thinnest (1.80 mm). The thickness of the leather from the remaining breeds did not differ from each other (~2.19 mm, $P$ >0.05). The lastometer distension values were similar ($P$ =0.971) between the different breeds, with an average value of 11.90 mm. Dorper, Meatmaster and White Dorper leather samples had the strongest tensile strengths (10.88, 12.32 and 10.02 N/mm$^2$, respectively), while leather from Dohne Merino, Merino and SAMM sheep had the weakest ($P$ ≤0.05) tensile strengths (6.19, 5.42 and 4.62 N/mm$^2$). The tensile strength of Dormer leather (6.72 N/mm$^2$) only differed significantly from that of Dorper and Meatmaster leather. A tendency ($P$ =0.059) was observed for leather from Dorper, Meatmaster and White Dorper to have a higher breaking force (~209.5 N) than that of SAMM leather (93.7 N). Leather from White Dorper sheep showed the greatest elongation at break, followed by that Dorper and Meatmaster breeds, which in turn were greater than that of Dohne Merino sheep (103.5, 82.9, 79.6 and 59.0%, respectively; $P$ ≤0.05). The elongation of Dormer, Merino and SAMM leather samples (~72.7%) only differed significantly from that of White Dorper leather.

Many trends observed in the leather qualities of Group 1 were reflected in Group 2 (Table 9.4), although to different magnitudes. As wool sheep were shorn about a month prior to slaughter, skin yields were lower than that observed in Group 1, with the highest yields ($P$ <0.001) being attained by Dohne Merino and Meatmaster sheep (7.2% and 7.0%, respectively) followed by Dorper and SAMM yields (both 6.3%), and White Dorper presenting the lowest yield (5.9%). Dormer skin yield (6.1%) did not differ ($P$ >0.05) from that of Dorper, SAMM and White Dorper sheep. It was observed that rams had a higher skin yield than that of ewes (6.8% *vs*. 6.2%, respectively; $P$ <0.001). The leather from rams was also thicker than that of ewes (1.80 mm *vs*. 1.37 mm, respectively; $P$ <0.001). Dormer samples had the thickest leather, which did not differ from that of Dohne Merinos (1.91 and 1.84 mm, respectively; $P$ >0.05), but did differ significantly from that of SAMM (1.63 mm), White Dorper (1.55 mm), Dorper (1.36 mm) and Meatmaster skins being the thinnest (1.24 mm). The effect of sex did not influence distension values ($P$ =0.367), while ($P$ =0.050) White Dorper and Dohne Merino samples (~13.86 mm) had higher distension values ($P$ =0.050) than Dorper and SAMM samples (12.38 mm). With regard to tensile strength no differences were observed between rams and ewes ($P$ =0.484), while White Dorper leather presented the highest ($P$ ≤0.05) values (18.59 N/mm$^2$), followed by Meatmaster (14.80 N/mm$^2$) and Dorper leather (12.70 N/mm$^2$) which in turn were markedly stronger than that of Dormer leather samples (7.08 N/mm$^2$). The tensile strengths of Dohne Merino and SAMM leather (~9.82 N/mm$^2$) did not differ significantly from that of Dorper or Dormer leather. The breaking force of leather from rams was 32.6% greater than that from ewes ($P$ =0.015), with the breaking force of White Dorper sheepskin leather (280.5 N) also being significantly greater than other breeds (~161.6 N). White Dorper leather also displayed the greatest elongation at break relative to the other breeds (77.2% *vs.* ~63.4%; *P* ≤0.05), while no differences were observed with the effect of sex (*P* =0.850).

After determining that there were differences between breeds, the sheepskin leather characteristics of pooled hair (Dorper, Meatmaster and White Dorper) and wool type (Dohne Merino, Dormer, Merino and SAMM) breeds from Group 2 were compared (Table 9.5). The skin yield, distension at crack and percentage elongation at break traits did not differ significantly between hair and wool type sheep. Although the leather from wool type sheep was 30.9% thicker than that of hair type sheep (*P* <0.001), the leather from hair type sheep had a higher tensile strength than wool type sheep (15.23 *vs*. 9.31 N/mm$^2$, respectively; *P* <0.001) and also tended to have a higher breaking force (205.87 *vs*. 168.58 N, respectively; *P* =0.074).

**Table 9.3** Sheepskin leather quality characteristics (least square means ± s.e.) of ewe and ram yearlings of different breeds reared under feedlot conditions, when skins were stored and dried for 18 months before tanning.

| Main effect | | *n* | Skin yield (%) | Leather thickness (mm) | Lastometer distension at crack (mm) | Tensile strength (N/mm$^2$) | Breaking force (N) | Percentage elongation at break (%) |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 29 | 10.6 ± 0.30 | 2.25 ± 0.118 | 11.42 ± 0.251 | 7.31 ± 0.686 | 152.3 ± 15.22 | 79.9 ± 3.18 |
| | Ram | 25 | 9.9 ± 0.33 | 2.37 ± 0.130 | 12.37 ± 0.276 | 8.75 ± 0.759 | 186.6 ± 16.82 | 75.3 ± 3.18 |
| | *P-value* | | *0.119* | *0.511* | *0.014* | *0.167* | *0.138* | *0.333* |
| | | | | | | | | |
| Breed* | Dohne Merino | 8 | 14.1$^{a}$ ± 0.57 | 2.55$^{ab}$ ± 0.228 | 12.03 ± 0.486 | 6.19$^{c}$ ± 1.333 | 154.9 ± 29.55 | 59.0$^{c}$± 6.17 |
| | Dormer | 8 | 9.9$^{b}$ ± 0.56 | 2.40$^{bc}$ ± 0.221 | 12.01 ± 0.470 | 6.72$^{bc}$ ± 1.290 | 159.1 ± 28.62 | 74.5$^{bc}$± 5.97 |
| | Dorper | 7 | 7.9$^{c}$ ± 0.66 | 1.80$^{c}$ ± 0.262 | 11.44 ± 0.557 | 10.88$^{a}$ ± 1.527 | 189.4 ± 33.86 | 82.9$^{b}$± 7.07 |
| | Meatmaster | 8 | 9.2$^{bc}$ ± 0.57 | 2.04$^{bc}$ ± 0.228 | 11.69 ± 0.486 | 12.32$^{a}$ ± 1.333 | 231.8 ± 29.55 | 79.6$^{b}$± 6.17 |
| | Merino | 8 | 13.4$^{a}$ ± 0.56 | 3.07$^{a}$ ± 0.221 | 11.96 ± 0.470 | 5.42$^{c}$ ± 1.290 | 149.9 ± 28.62 | 74.8$^{bc}$± 5.97 |
| | SA Mutton Merino | 8 | 8.7$^{bc}$ ± 0.60 | 2.13$^{bc}$ ± 0.239 | 12.05 ± 0.508 | 4.62$^{c}$ ± 1.394 | 93.7 ± 30.91 | 68.8$^{bc}$± 6.45 |
| | White Dorper | 7 | 8.7$^{bc}$ ± 0.56 | 2.18$^{bc}$ ± 0.221 | 12.09 ± 0.470 | 10.02$^{ab}$ ± 1.290 | 207.3 ± 28.62 | 103.5$^{a}$± 5.97 |
| | *P-value* | | *<0.001* | *0.012* | *0.971* | *<0.001* | *0.059* | *<0.001* |

$^{a\text{-}c}$ Means with different superscripts in columns differ (*P* ≤0.05).

* Wool breeds were not shorn prior to slaughter.

**Table 9.4** Sheepskin leather quality characteristics (least square means ± s.e.) of ewe and ram yearlings of different breeds reared under feedlot conditions, when skins were stored and dried for 9 months before tanning.

| **Main effect** | | ***n*** | **Skin yield (%)** | **Leather thickness (mm)** | **Lastometer distension at crack (mm)** | **Tensile strength ($N/mm^2$)** | **Breaking force (N)** | **Percentage elongation at break (%)** |
|---|---|---|---|---|---|---|---|---|
| Sex | Ewe | 66 | 6.2 ± 0.07 | 1.37 ± 0.050 | 12.89 ± 0.242 | 12.52 ± 0.750 | 160.3 ±14.29 | 65.9 ± 1.66 |
| | Ram | 60 | 6.8 ± 0.08 | 1.80 ± 0.055 | 13.21 ± 0.264 | 11.74 ± 0.817 | 212.6 ±15.55 | 65.4 ± 1.81 |
| | *P-value* | | *<0.001* | *<0.001* | *0.367* | *0.484* | *0.015* | *0.850* |
| | | | | | | | | |
| Breed* | Dohne Merino | 21 | $7.2^{a}$ ± 0.13 | $1.84^{ab}$ ± 0.090 | $13.80^{a}$ ± 0.437 | $9.77^{cd}$ ± 1.344 | $175.2^{b}$ ± 25.59 | $64.3^{b}$ ± 2.97 |
| | Dormer | 17 | $6.1^{bc}$ ± 0.14 | $1.91^{a}$ ± 0.098 | $12.96^{ab}$ ± 0.466 | $7.08^{d}$ ± 1.453 | $140.7^{b}$ ± 27.67 | $64.0^{b}$ ± 3.21 |
| | Dorper | 19 | $6.3^{b}$ ± 0.14 | $1.36^{cd}$ ± 0.099 | $12.43^{b}$ ± 0.437 | $12.70^{bc}$ ± 1.476 | $176.1^{b}$ ± 28.12 | $61.6^{b}$ ± 3.26 |
| | Meatmaster | 29 | $7.0^{a}$ ± 0.11 | $1.24^{d}$ ± 0.076 | $12.85^{ab}$ ± 0.358 | $14.80^{b}$ ± 1.133 | $177.5^{b}$ ± 21.58 | $64.2^{b}$ ± 2.51 |
| | SA Mutton Merino | 21 | $6.3^{b}$ ± 0.13 | $1.63^{bc}$ ± 0.090 | $12.32^{b}$ ± 0.431 | $9.86^{cd}$ ± 1.344 | $168.6^{b}$ ± 25.59 | $62.7^{b}$ ± 2.97 |
| | White Dorper | 19 | $5.9^{c}$ ± 0.13 | $1.55^{cd}$ ± 0.092 | $13.91^{a}$ ± 0.455 | $18.59^{a}$ ± 1.374 | $280.5^{a}$ ± 26.16 | $77.2^{a}$ ± 3.04 |
| | *P-value* | | *<0.001* | *<0.001* | *0.050* | *<0.001* | *0.008* | *0.005* |

$^{a-d}$ Means with different superscripts in columns differ (*P* ≤0.05).

* Wool breeds were shorn one month prior to slaughter.

**Table 9.5** Sheepskin leather quality characteristics (least square means ± s.e.) of pooled hair (Dorper, Meatmaster and White Dorper) and wool (Dohne Merino, Dormer, Merino and SA Mutton Merino) sheep type yearlings reared under feedlot conditions, when skins were stored and dried for 9 months before tanning.

| **Trait** | **Hair type** | **Wool type** | ***P-value*** |
|---|---|---|---|
| *n* | 67 | 64 | |
| Skin yield (%) | 6.5 ± 0.10 | 6.6 ± 0.10 | *0.374* |
| Leather thickness (mm) | 1.36 ± 0.059 | 1.78 ± 0.059 | *<0.001* |
| Lastometer distension at crack (mm) | 13.04 ± 0.240 | 13.06 ± 0.246 | *0.948* |
| Tensile strength (N/mm$^2$) | 15.23 ± 0.748 | 9.31 ± 0.760 | *<0.001* |
| Breaking force (N) | 205.9 ± 14.5 | 168.6 ± 14.8 | *0.074* |
| Percentage elongation at break (%) | 67.3 ± 1.72 | 63.3 ± 1.74 | *0.100* |

## 9.4 Discussion

While rearing and slaughter conditions of the sheep from both production groups reared under optimal growth conditions on the respective trial diets, the main factors that varied were the shearing of wool sheep prior to slaughter (Group 2) as well as the period for which skins were dried and stored (18 months *vs.* 9 months). However, it is not clear which of these factors may have contributed the greatest influence on the poorer leather properties observed in Group 1. While skins were thoroughly salted relative to the weight of the skin to limit microbial growth, the presence of longer wool in Group 1 increases the likelihood of water vapour sorption (Ling, 1965) even when skins have been dried. With the microorganisms obtained from the air, water, soil, manure and handling, ideal conditions are then created for contamination and microbial growth which is responsible for the degradation of untanned proteins (Orlita, 2004). With prolonged storage prior to tanning, even if the skins have been properly cured, the risk of microbial degradation of proteins increases, and so weakens the physical properties of the leather. Abattoirs and tanneries should therefore reduce curing and storage times of skins prior to tanning to improve the physical properties of sheepskins.

The presence of longer wool also increases the weight of the skin, which then requires a greater amount of water and chemicals to soak, lime and bate the skins in order to remove the wool (Table 9.1). Some products require wool-on leather when skins with wool (fibre diameter <31 μm) are tanned by a process that retains the wool on the pelt (Passman & Sumner, 1983; Scobie *et al*., 1997). Alternatively, long wool can be clipped from the skin after slaughter, which reduces the weight of the skin for curing and tanning, while also yielding an income from the harvested wool. Cloete *et al*. (2012) reported skin yields of 6.4% for yearlings, with Merino yearlings recording relatively heavier skins (8.4%) due to the greater quantity of wool growth. Skin growth is approximately relative to live weight, while skin surface area (body weight$^{2/3}$) would be early maturing relative to live weight, however, thickness of the skin continues to increase resulting in the increase in skin weight after maturity (Butterfield, 1988). Salehi *et al.* (2014) observed that skin weight and physical strength of leather from male goats was greater than that of females, as well as being greater in mature goats than leather produced from kid skins. Passman & Sumner (1987) also observed that the skin weights and physical characteristics of the leather increased with slaughter weight and age of lambs.

After tanning, the damp wet blues were shaved to remove excess flesh and fat and to reduce the thickness of the skin to that desired in the final leather. Sheepskins intended for nappa leather are usually shaved to a thickness of 0.7-0.9 mm; however, skins with weaker properties cannot be shaved to this extent, due to damage to the wet blue, and must therefore be kept thicker (Snyman & Jackson-Moss, 2000). Skins from wool sheep breeds, in particular Merino sheep, are associated with a high incidence of ribbing resulting from skin pleats, which makes the leather weaker due to damage and stress to the skin caused during shearing and flaying (Scobie *et al*., 2006). Wool sheep breeds have also been associated with the occurrence with neck and mottle markings on the skin, which make it unsuitable for nappa leather production due to the aesthetic as well as weakened properties of the leather (Hughes *et al*., 1978; Passman & Dalton, 1982). The incidence of mottle, though, can be improved by raising the liming temperature to 30°C (Hughes *et al*., 1978). These characteristics result in skins of wool sheep having weaker properties making them prone to breakage and are therefore not shaved properly. These thicker skins are then more suited be used as suede leather for chamois cloths rather than nappa leather (Jackson-Moss, C.A. Pers. Comm.).

The effect of sex had a minor influence on the physical leather properties in the two production groups, with Group 2 rams producing thicker leather with a higher breaking force than ewes, but showing similar tensile strengths and extension. Previous work on the physical properties of leather of South African sheep breeds reported tensile strengths ranging from 11.86-22.56 N/mm$^2$, elongation of 54.0-89.0% at break and lastometer distensions of 11.52-13.12 mm (Snyman & Jackson-Moss, 2000). In their study, the stronger leather properties were observed in Damara, Van Rooy and Blackhead Persian hair sheep breeds, while the weaker properties were observed in Merino and Dormer breeds. The current study showed that there were differences in skin thickness and tensile strength between hair and wool type sheep (Table 9.5), while differences were more clearly outlined when evaluating the differences between the specific hair and wool type breeds (Table 9.3 and 9.4). White Dorper, Meatmaster and Dorper sheep breeds produced skins with the strongest characteristics in this study, while Dohne Merino, Merino, Dormer and SAMM skins showed considerably weaker characteristics, particularly the skins sampled from Group 1. The Damara, Van Rooy and Dorper breeds have been linked as ancestors used in the development of the Meatmaster

(Peters *et al*., 2010), while the Blackhead Persian in turn was used in the development of the Dorper (Milne, 2000). The ancestral links may suggest the heritability of skin properties owing to stronger leather characteristics. The Dorper, Dormer and Merino breeds were evaluated in both the current study, as well as the study by Snyman & Jackson-Moss (2000), with the properties following the same trends in both studies, although, the magnitudes of the values of the current study were lower than that reported by the previous study. The reason for the differences may be as a result of the prolonged time of curing and storage followed in the current study. Urge *et al.* (2017) reported tensile strengths of 18.2-19.2 N/mm$^2$ and distensions of 9.7-10.1 mm for fat-tailed sheepskins with a thickness of 0.53 mm. Hair sheep breeds thus produce a leather product that is more compatible with leather industry requirements (Urge *et al*., 2017). Jacinto *et al.* (2004) reported that wool sheep breeds yield skins with tensile strengths below 9.0 N/mm$^2$, again confirming the weaker properties of skins from wool breeds.

Sliping of wool from the skins of wool breeds can be used as a technique to improve income generation of the lower quality skins by selling the sliped wool for rug or clothing manufacturing (Hughes *et al*., 1978; Passman & Sumner 1987). Alternatively, if the bulk density of wool is sufficient, the skins can be tanned to produce wool-on leather for medical use, or sueded shearling for clothing use (Passman & Sumner, 1983). It is recommended that skins with a staple length of 25-50 mm be used to produce for wool-on skins (Holst *et al*., 1996). The differences in leather properties of the various breeds can also be improved by adjusting tanning processes and chemicals of skins of a particular breed, so as to produce a desirable product with better aesthetic and physical properties (Passman & Sumner 1987; Merkel *et al*., 2013), although the exact adjustments required would need to be researched further. Applying different tanning techniques to skins of different breeds may result in leather products that are more suited to the characteristics of the skins of the respective breeds, while possibly improving the physical characteristics, providing leather of a greater value. The implementation of different tanning techniques may also reduce the processing costs of the end product.

## 9.5 Conclusion

It is clear that the physical quality characteristics of sheepskins from different breeds differ, with hair breeds producing skins with stronger leather properties. The weaker leather properties of wool breeds limit the extent to which the skins can be shaved. In this study, sex had little influence on the quality characteristics of the leather. However, it was observed that the prolonged periods in which skins were cured and stored prior to tanning may have resulted in microbial damage which weakens the physical properties of the leather. Further research may be needed on optimal curing conditions and the period that cured skins can be stored prior to tanning. In practice, in smaller operations, salted skins may be stored for a few months before reaching the tanning stage and further investigation is needed so as to ensure the quality of the leather product.

## References


Ballard, R., 2001. A preliminary study on the bovine leather value chain in South Africa. CSDS Research Report No. 40 University of Natal, Industrial Restructuring Project, School of Development Studies (SDS).

Brand, T.S., Van der Westhuizen, E.J., Van der Merwe, D.A., Hoffman, L.C., 2017. Effect of days in feedlot on growth performance and carcass characteristics of Merino, South African Mutton Merino and Dorper lambs. S. Afr. J. Anim. Sci., 47, 26-33.

Butterfield, R.M., 1988. New concept of sheep growth. The Department of Veterinary Anatomy, University of Sydney. pp 1-33.

Cloete, J.J.E., Hoffman, L.C., Cloete, S.W.P., 2012. A comparison between slaughter traits and meat quality of various sheep breeds: Wool, dual-purpose and mutton. Meat Sci., 91, 318-324.

Department of Agriculture, Forestry & Fisheries. 2019. Abstract of Agricultural statistics. DAFF: Directorate statistics and economic analysis, South Africa. pp 61-65. (https://www.daff.gov.za/Portals/0/Statistics%20and%20Economic%20Analysis/Statistical%20Information/Abstract%202019.pdf?timestamp=1568549611726 ).

Ekiz, B., Demirel, G., Yilmaz, A., Ozcan, M., Yalcintan, H., Kocak, O., Altinel, A., 2013. Slaughter characteristics, carcass quality and fatty acid composition of lambs under four different production systems. Small Rumin. Res., 114, 26-34.

Holst, P.J., Hegarty, R.S., Fogarty, N.M., Hopkins, D.L., 1997. Fibre metrology and physical characteristics of lambskins from large Merino and crossbred lambs. Aust. J. Exp. Agric., 37, 509-514.

Holst, P., Hopkins, D., Stanley, D., 1996. Time required post-shearing to attain desirable wool lengths for lambskins from different genotypes. Wool Tech. Sheep Breed. 44, 290-294.

Hughes, I.R., Peters, G.P., Dalton, D.C. 1978. Wool and leather production from 15-month-old wethers of different breeds on hill country, New Zeal. J. Agric. Res., 21, 383-388.

ISO. 2002a. ‘ISO 2418. Method for the leather – chemical, physical, mechanical and fastness tests Sampling location. International Organization for Standardization: Geneva, Switzerland

ISO 2002b. ‘ISO 2589. Method for the determination of thickness. International Organization for Standardization: Geneva, Switzerland.

ISO 2002c. ‘ISO 3376. Method for the determination of strength and percentage extension. (IULTCS/IUP 6). International Organization for Standardization: Geneva, Switzerland.

Jacinto, M.A.C., Silva Sobrinho, A.G.D., Costa, R.G., 2004. Anatomical-structural characteristics of wool-on and non-wool sheep skins related to the physical-mechanic leather aspects. *R. Bras. Zootec.,* 33,1001-1008.

Jacinto, M.A.C., Vargas Junior, F.M.D., Martins, C.F., Pinto, G.D.S., Reis, F.A., Oliveira, A.R.D., 2011. Influence of genotype on the quality of sheep leather. *R. Bras. Zootec.,* 40, 1830-1836.

Jackson-Moss, C.A. International School of Tanning Technology, Grahamstown, South Africa.

Ling, G.N., 1965. The physical state of water in living cell and model systems. Ann. N. Y. Acad. Sci., 125, 401-417.

Merkel, R.C., Liu, C.K., Latona, N., El Amma, A., Goetsch, A.L., 2013. Effects of level and length of supplementation on leather characteristics of yearling boer and Spanish wethers. J. Am. Leather Chem. Ass., 108, 139-145.

Milne, C., 2000. The history of the Dorper sheep. Small Rumin. Res*.,* 36, 99-102.

Notter, D.R., Kelly, R.F., McClaugherty, F.S., 1991. Effects of ewe breed and management system on efficiency of lamb production: II. Lamb growth, survival and carcass characteristics. J. Anim. Sci., 69, 22-33.

Orlita, A., 2004. Microbial biodeterioration of leather and its control: a review. Int. biodeter. & biodegr., 53, 157-163.

Passman A., Dalton D. C. 1982. Influence of Romney, Coopworth, and Perendale breeds on lambskin leather quality, New Zeal. J. Exp. Agric.,10, 7-13.

Passman, A., Sumner, R.M.W., 1983. Effects of breed and level of feeding on leather production from 18-month-old wethers. New Zeal. J. Exp. Agric, 11, 47-52.

Passman, A., Sumner, R.M.W. 1987. Effects of breed and age at slaughter on leather produced from export lambs reared on hill country. New Zeal. J. Exp. Agric*,* 15, 309-316.

Peters, F.W., Kotze, A., Van der Bank, F.H., Soma, P., Grobler, J.P., 2010. Genetic profile of the locally developed Meatmaster sheep breed in South Africa based on microsatellite analysis. Small Rumin. Res*.,* 90, 101-108.

Salehi, M., Kadim, I., Mahgoub, O., Negahdari, S., Naeeni, R.E., 2014. Effects of type, sex and age on goat skin and leather characteristics. Anim. Prod. Sci., 54, 638-644.

Scobie, D.R., Cooper, S.M., Passman, A., Young, S.R., 1997. Bulk and fibre diameter affect leather and woolskin quality of lamb skins. Proc. New Zeal. Soc. Anim.Prod. 57, 77-80.

Scobie, D.R., Young, S.R., O'Connell, D., Eythorsdottir, E., 2006. Skin wrinkles of the sire adversely affect Merino and halfbred pelt characteristics and other production traits. Aust. J. Exp. Agric., 45, 1551-1557.

Snyman, M.A., Jackson-Moss, C.A., 2000. A comparison of leather properties of skins from ten different South African sheep breeds. S. Afr. J. Anim. Sci., 30: 129-130.

Tshabalala, P.A., Strydom, P.E., Webb, E.C., De Kock, H.L., 2003. Meat quality of designated South African indigenous goat and sheep breeds. Meat Sci., 65, 563-570.

Urge, M., Ayele, S., Animut, G., Kurtu, M.Y., 2017. Skin and Leather Quality of Ethiopian Indigenous Fat-tailed Hair Sheep as Affected by Breed and Level of Concentrate Supplementation. East Afr. J. Vet. Anim. Sci., 1, 101-110.

# Chapter 10 General conclusions and recommendations

This dissertation was undertaken in order to develop models that can be used to predict the production and ideal slaughter weights of lambs of different South African sheep breed types. In order to compile a decision support system that can be used to predict the feedlot production characteristics of South African sheep breeds, studies were carried out to model the growth, feed intake, back-fat depth (measured using an ultrasound scanner) as well as the wool growth of wool type breeds. Studies were also carried out to determine the feedlot production characteristics and ideal slaughter weight of the different breeds, as well as to compare the carcass quality characteristics of premium lamb carcasses from the various breeds. Additionally, the leather quality characteristics of the skins of different breeds were investigated. The models developed for growth, intake, back-fat depth and fleece growth, provide the first models developed for South African sheep breeds reared under optimal growth conditions up to a mature body weight attained at ~1 year of age. It is also the first study that compares six or seven South African sheep breeds that are reared together under the same conditions. The breeds that were incorporated in the studies include the Merino which is considered to be a wool sheep breed, dual-purpose Dohne Merino (wool orientated) and South African Mutton Merino (SAMM) (meat orientated) breeds, along with the coarse-wooled Dormer breed which is considered to be a terminal sire breed. Hair sheep breeds that were included were the Dorper and White Dorper breeds as well as the fat-tailed Meatmaster and Namaqua Afrikaner (indigenous) breeds. This dissertation also contains the first documentation of the growth performance and meat and leather product quality characteristics of the Meatmaster breed.

The main differences observed in the various studies presented in this dissertation can be explained by the differences in mature weights and maturity of the different breeds. Generally, it is observed that larger animals with heavier mature weights attain maturity at a later stage than animals with lighter mature weights. With respect to the differences between sexes, rams have higher mature weights than ewes, and therefore exhibit higher growth rates; while ewes attain maturity earlier and deposit fat at lighter body weights so influencing subcutaneous fat cover and feeding efficiency. Dormer and SAMM breeds attained the highest mature body weights, while early maturing hair sheep and wool breeds presented lighter mature weights. By modelling the ultrasound back-fat depth of the different breeds, it was observed that White Dorper and Meatmaster breeds are early maturing relative to Dorper, followed by Dohne Merino, Dormer and SAMM breeds. Additionally, in the study to determine the optimum slaughter weights of different breeds to produce a premium lamb carcass, Namaqua Afrikaner sheep were found to be early maturing due to their lighter mature weights and high fat deposition in the tail depot, while the ideal slaughter weights of Merino lambs resembled that of the later maturing breeds. Therefore, Namaqua Afrikaner, White Dorper and Meatmaster can be considered as early maturing breeds, followed by Dorper sheep being relatively medium maturing and Merino, Dohne Merino, Dormer and SAMM sheep being regarded as later maturing breeds.

The Logistic, Gompertz and Von Bertalanffy functions were found to be suitable in modelling the growth curves of the various production groups, while the Brody function was found to overestimate the body weights of the lambs. Care though should be taken in the application of the Logistic model as it tended to overestimate early preweaning growth of the lambs. The amount of feed that a lamb consumes influences its capacity for growth, however, feed intake is also a function of body weight. Models were thus developed in order to predict voluntary feed intake of growing lambs. Quadratic functions were fitted to describe the difference in daily feed intake with body weight with moderate to low coefficients of determination for the respective production groups. It must be remembered that feed intake is influenced by animal, feed as well as environmental factors. This study therefore provides a baseline model describing the change in daily feed intake in growing lambs, to which other feed composition and environmental factors can be added in order to obtain more accurate predictions. By modelling the daily intake expressed as a percentage of body weight, more applicable linear functions were obtained to describe the decrease in percentage intake as the lambs increase in body weight. Linear functions describing the cumulative feed intake over the entire rearing period from weaning (~3 months) up until maturity (~1 year of age) explained most of the variation of the data. However, using cumulative feed intake models could be problematic, as they are applicable to the specific rearing period; also, knowledge of the growth rate at the specific body weight is required in order to obtain values for daily feed intake. Differentiation of the growth models provides curves describing the change in growth rate, which can be incorporated to calculate daily feed intake from cumulative intake models. Exponential functions were used to model the change in feed conversion ratio with body weight. With breeds following similar trends to intake curves, with Dormer lambs exhibiting higher intakes with extended time in feed, reducing feeding efficiency. Early maturing breeds such as Meatmaster and White Dorper lambs also showing steep increases in feed conversion ratio with increased fat deposition. Feed conversion ratios of SAMM lambs were seen to increase at a much slower rate with the increase in body weight.

The use of ultrasound technology made it possible to measure back-fat and muscle tissue depths of the growing lambs. The exponential function was again used to model the change in back-fat depth with body weight of the lambs. This allowed for predictions to be made regarding the subcutaneous fat cover of the lambs at a given body weight, as well as highlight the differences in physiological maturity, with regard to fat deposition, between the different breeds. Moderate to high coefficients of determination were obtained for linear regressions relating ultrasound back-fat depth with age of the lambs. This was achieved as lambs were reared under optimal growth conditions and therefore there was a close positive correlation between age and body weight, as shown by the growth curves. Under sub-optimal circumstances, body weight will be a more accurate predictor of back-fat depth than age as a result of decreased growth rates. As *longissimus* muscle tissue depths are often incorporated in determining carcass composition, and also included as a selection criterion in breeding programs, power curves were found to be most applicable in describing the growth in tissue depth with low to moderate coefficients of determination. The models for predicting back-fat depth can be incorporated into precision rearing systems to determine carcass value with respect to the degree of fat cover, while muscle depth models can also be incorporated in the correction of breeding systems.

In the subsequent studies, the use of ultrasound technology was also used to identify the ideal point of slaughter by monitoring lambs on a weekly basis and slaughtering them as they near the desired back-fat depth for a premium lamb carcass (4 mm). The ideal slaughter weights of the breeds that were used in this study to produce a premium lamb carcass are indicated in Table 10.1, with the weights of ewes being ~10% lower than that of rams. These proposed slaughter weights also closely resemble that predicted by the back-fat model developed using the exponential function.

**Table 10.1** Reccomended ideal slaughter weights of rams and ewes of South African sheep breeds in order to produce a premium lamb carcass with a back-fat depth of 4 mm

| Breed | Ideal slaughter weight (kg) | |
|---|---|---|
| | Ewes | Rams |
| Dohne Merino | 39 | 48 |
| Dormer | 42 | 43 |
| Dorper | 37 | 39 |
| Meatmaster | 33 | 37 |
| Merino | 38 | 45 |
| Namaqua Afrikaner | 33 | 32 |
| SA Mutton Merino | 41 | 47 |

From Table 10.1, it can be seen that the proposed slaughter weights of early maturing lambs (Namaqua Afrikaner, Meatmaster and Dorper) are lighter than that of the later maturing breeds due to the earlier onset of fat deposition. As a result, these early maturing breeds also exhibit a shorter rearing period to the lighter slaughter weight. As a result, feedlot operators tend to discriminate against rearing early maturing breeds in commercial feedlots, due to lower returns on investment being received with the lower weights. Later maturing breeds can be reared for a longer period to gain weight and market a heavier carcass at slaughter. The differences in slaughter weight between ewes and rams from the wool-type breeds are more defined than that of the early maturing and Dormer breeds. Rearing meat type breeds such as Dormer and SAMM ram lambs with improved growth rates and feeding efficiencies, reduces the rearing period and amount of feed to rear the lambs, while still obtaining a heavier carcass. Dorper and Meatmaster lambs can still be reared in feedlots with reasonable efficiency, producing narrow profit margins; while due to the low growth rates and feeding efficiency experienced by Namaqua Afrikaner, along with the lighter slaughter weight, it is unfeasible to profitably rear these lambs in a feedlot.

Evaluating the carcass quality characteristics of premium lamb carcasses produced from the different production groups, ewe lambs produced a carcass with a greater proportion of fat and less lean and bone tissue. With small differences in quality characteristics, that are not necessarily detected by untrained consumers, being observed between breeds; the present carcass classification system is well suited to describe the physical meat quality of carcasses from the different breeds. However, the classification system does not take fat-tailed breeds into account in the prediction of carcass composition, as these breeds have large deposits of fat on the rump surrounding the tail, while the rest of the carcass is relatively lean. The different breeds also present different frame sizes and conformations at the respective ideal points of slaughter which influences the yields as well as the proportion of lean tissue of the retail cuts.

Wool is an extra commodity which can be used to supplement the income derived from sheep production. Merino sheep exhibit the highest wool growth rates, producing the heaviest fleece with the smaller fibre diameters. In this study, the wool growth rates and fleece rates of the dual-purpose Dohne Merino and SAMM lambs did not differ significantly, while the Dohne Merino fleeces were found to be finer than that of SAMM fleeces. Dormer lambs showed the slowest wool growth producing the lightest fleeces with a coarse (>27 μm) fibre diameter. Linear regressions were developed to estimate the fleece weight of the growing lambs of different breeds. These models can be incorporated into a decision support system in order to make predictions to assist producers in deciding to shear their lambs before sending them for slaughter.

An additional study was also undertaken to investigate the leather properties produced from skins obtained from the different breeds at slaughter. Skins obtained from hair sheep breeds (Dorper, Meatmaster and White Dorper) produced higher quality leather that could be shaved to a thinner, more pliable thickness with stronger properties. Leather from wool breeds exhibited weaker, less desirable, properties and it is advised that skins from these breeds be tanned to produce leather products with characteristics more suited to the properties of leather from these breeds. It was also observed that time spent during curing and storage of skins prior to tanning may have an influence on the strength properties of the sheepskin leather.

Considering the costs associated with the tanning of skins, further research may be directed in optimising curing and storage conditions and times, in order to ensure that high quality leather with desirable characteristics is produced.

As the models developed in the presented studies provide a baseline for a decision support system, it is recommended that the size of the databases be increased by continuing to collect data and updating the models in order to ensure that they remain accurate and relevant. As crossbreeding of terminal sire rams with wool type ewes is a common practice to improve the meat production of the lambs, it is suggested that the growth curves of various crosses be determined and incorporated along with the growth models of the pure breeds and be used to predict ideal slaughter weights of these crossbreeds. The trends of feed intake and fat deposition of these crossbred lambs should also be investigated up until maturity. Further studies regarding the prediction of feed intake are also required. Evaluating the effects of the nutritional composition and physical form of the diet, as well as environmental factors, on the feed intake of growing lambs from the different breeds should be investigated. It is also advised that in modelling the feed intake of feedlot lambs, up until mature body weights, that fat deposition measurements be included in the model along with body weight as this may elucidate the trends that intake follows as lambs near mature body weights. These fat deposition measurements can be made using ultrasound technology which proved useful in the studies presented in this dissertation. The use of ultrasound measurements in modelling the increase in fat depth in this study was the first recorded attempt in determining fat deposition in growing lambs from South African breeds over an extended rearing period. The use of ultrasound technology is currently underutilised in monitoring fat deposition of live animals and could be used in monitoring the fat depth in growth and nutrition studies as well as used to assess the body condition of ewes. As fat deposition patterns of different breeds vary, it is recommended that ultrasound measurements be made at additional sites on the body in order to obtain a clearer picture of fat deposition around the body. This could then be used as a tool that can be incorporated in selection programs, allowing producers to breed for enhanced lean muscle growth or a more uniform fat depth around the carcass.

It is also suggested that the meat quality characteristics of yearling lambs be assessed, to determine if these traits fall within an acceptable range for South African consumers. This will determine whether the meat can be regarded as lamb rather than mutton, as is the scenario that has been developed in the Australian and New Zealand sheep industries. This development allows farmers to rear lambs on pasture for longer and obtain an acceptable fleece before lambs are slaughtered at an older age (two-tooth lambs). As sheep are slaughtered, skins are also obtained from the process that has the potential of being produced into high value leather products. With this additional product being obtained from sheep, more research is needed on the different tanning processes that can be applied to the skins of different breeds in order to enhance the leather characteristics and so maintain the profitability of the expensive tanning process.

The models developed in this dissertation can be used to run simulation and predict the possible outcomes within a lamb feedlot system, based on the growth, feed intake and fat deposition of the different breeds. This can then be used to determine the profitability of the system and identify the optimal point of slaughter. Looking at the differences in product quality and yields of meat, wool or leather, informed decisions can be made by the producer as well as processor in determining the best marketing strategies in order to obtain optimal profitability from the lambs of different breeds. Using these tools, precision rearing and marketing of lambs can be practised to improve production of intensive lamb rearing systems.